THE UNIVERSITY OF ALBERTA

NATURAL SELECTION IN A COMPOSITE CROSS OF BARLEY

by

©

LAXMI NARAIN SINGH

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GENETICS

EDMONTON, ALBERTA

AUGUST, 1967

ABSTRACT

A composite of 105 crosses involving 15 parental varieties of barley was grown for five years at nine stations of widely different latitudes. After five years of cultivation at each station a resulting sample was obtained and grown for comparative study in 1964 and 1965 at Parkland Farm, University of Alberta, Edmonton. Considerable differences were observed among the samples from different stations regarding heading date, maturity date and yield. Very little difference was observed for height of the plant and thousand-kernel weight. Natural selection acted strongly against the black kernels and their proportions showed marked reduction at all stations. Elimination of black kernel seems to be due to its linkage with some characters of low competitive capacity.

Differential selection was observed for spike and awn types. The proportions of two-rowed spikes and rough awns increased at some stations and decreased at others, which may be attributed to natural selection. Natural selection had very little effect upon the collar type, neck shape and leaf width. Shape of basal rachis internode and neck length were not influenced by the stations at which seed was grown.

ACKNOWLEDGEMENTS

I wish to express sincere appreciation to Dr. L.P.V. Johnson for organizing the project and for his assistance during the investigation and preparation of this manuscript.

Thanks are also given to Dr. W. E. Smith, Dr. R. Aksel, Dr. W. Combs, Dr. H. J. Brodie, Dr. N. Colotelo and Dr. C. A. Suneson for reading the manuscript and making valuable suggestions. I appreciate the financial assistance I received from a National Research Council of Canada grant, awarded to Dr. Johnson, that made this study possible.

The writer is also very grateful to Miss Margaret Maclean for her patience and industrious effort in typing the manuscript.

CO-OPERATORS

The author gratefully acknowledges the co-operation of the following who augmented the studies at Edmonton and made the experiment possible:

Dr. D. G. Faris, Research Station, Beaverlodge, Alberta; Mr. J. A. Gilbey and Mr. W. A. Russell, Research Station, Fort Simpson, N.W.T.; Mr. W. H. Hough and Mr. J. Y. Tsukamoto, Research Station, Mile 1019, Whitehorse, Yukon Territory; Mr. A. D. McFadden, Research Station, Lacombe, Alberta; Dr. R. A. Nilan, Department of Agronomy, State College of Washington, Pullman, Washington, U. S. A.; Prof. Ø. Nissen and Dr. E. Strand, Department of Farm Crops, Agricultural College of Norway, Vollebekk, Norway; Dr. C. A. Suneson, Department of Agronomy, University of California, Davis, California, U. S. A.; Dr. S. A. Wells, Research Station, Lethbridge, Alberta.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

(continued)

LIST OF ILLUSTRATIONS

" . ... Nature's productions should be far 'truer' in character than man's productions; that they should be infinitely better adapted to the most complex conditions of life, and should plainly bear the stamp of far higher workmanship?"

Charles Darwin (1859)

INTRODUCTION

The handling of large numbers of hybrids separately becomes quite troublesome; thus, cultivation of hybrids in bulk for a few generations has been recommended by some workers (Love, 1927; Harlan and Martini, 1929; Florell, 1929; Harrington, 1937; Suneson, 1956). Under a few years of bulk culvitation low yielding and disease susceptible types would be eliminated by natural selection because of high correlation between the competitive abilities of plants and the certain desirable agronomic characters. In F_7 or F_8, the composite population would contain large numbers of homozygous lines with superior germ plasm, and individual plant selection at this stage would be generally effective.

Differential selection in a composite population at different locations has been reported. This led to the present investigation in which nine locations were selected for the cultivation of bulk hybrids (105 crosses) for five years. The locations selected provided a wide range of such factors as latitude, altitude, precipitation, day length and temperature.

The main purpose of this research was to study the changes brought about by natural selection in different environmental conditions in a composite cross of barley, especially changes in genetic composition arising from the differential adaptability of some morphological characters under conditions of strong competition.

REVIEW OF LITERATURE

Natural selection and its various aspects have been discussed by Darwin (1859), Haldane (1932), Mather (1943), Anderson (1949), Stebbins (1950), Dobzhansky (1951), Simpson (1953), Fisher (1958), Lerner (1959), Sheppard (1960) and Grant (1963). The importance of natural selection in selecting agronomically desirable types in the bulk method of breeding is described by Newman (1912), Love (1927), Hays and Garber (1927) and Allard (1960). Harlan and Martini (1929) suggested that an intercrossing program could be undertaken to advantage in a situation where there are varieties which are not good enough to distribute but are too good to discard. This could allow superior types to show up.

Since the handling of large numbers of hybrids separately is troublesome, Harlan and Martini (1929) suggested that hybrids can be grown in bulk for a few generations. After a few years of cultivation in bulk the weaker combinations would be eliminated by natural selection, and the population would contain a large number of homozygous lines. Thereafter good varieties can be produced by making individual plant selection on the basis of desirable characters.

Nineteen wheat hybrids were grown biannually in bulk by Florell (1929) from 1923 to 1926 inclusive. Selections were made in 1926 and head rows were grown in 1927. Out of the best 45 selections grown in 1928, 33 selections yielded above the average yield of all check rows. Florell suggested that, in the bulk method of breeding, material should be grown in a large area to increase the chances of obtaining superior types. He also stated that this method can be used efficiently for such characters as winterhardiness, rust resistance, smut resistance, etc., in closely self-fertilized cereals.

Harrington (1937) described a mass-pedigree method of breeding for cereal crops, which is a combination of both mass and pedigree methods. This method involves less progeny-testing and therefore more crosses can be handled. If the progeny testing is made in F_4 or F_5, it would be less laborious than using the pedigree method. Some disadvantages in the mass-pedigree method are that it takes a year longer and leads to less critical selection in at least two of the segregating generations because of lack of pedigree record.

Harrington (1940) reported that, in wheat, bulk F_2 yield trials can be used in predicting the subsequent yield performance of F_6, F_7 and F_8 selections.

A very important study of natural selection in cereal crops was made by Harlan and Martini (1938). A mixture of eleven varieties of barley was grown from 4 to 12 years at 10 experimental stations. In the final year census, a sample of 500 plants was analyzed for the number of plants of each variety remaining in the population. Some poorly adapted varieties, e.g., Deficiens and Meloy, were eliminated at all locations. The elimination was much more rapid at some places than the others. Proportions of Coast and Trebi were very high in the mixture at most of the locations. This was due to the fact that Coast was well adapted to the west while Trebi was well adapted to the region from Idaho east. These varieties made a poor showing only at Moro (Oregon) because of the competition with White Smyrna which is an excellent variety for arid conditions.

Hannchen and White Smyrna were also found well adapted at most of the stations. Differences between the dominant variety and the variety which was grown by farmers in the vicinity were found in two instances.

At Ithaca (N.Y.), Manchuria became absolutely dominant, whereas most of the commercial acreage is in Alpha, a two-rowed variety very similar to Hannchen. Similarly at St. Paul (Minn.) Hannchen became predominant, but Manchuria constitutes the greater part of the commercial acreage there. Because of seasonal variations some varieties increased for a time and then decreased. Few varieties survived at all stations. It was found that the elimination of the poorest type occurred very quickly. The proportion of the second best variety did not start to decline until the best variety constituted one-half of the total population. The last plants of all varieties were slow to disappear. Harlan and Martini stated that the number of plants of a given variety that will be present in any year will depend on the number of seeds sown and on the percentage of survival of the seedlings in competition.

A study comparing the pedigree method of breeding with a composite where all the crosses were mixed together was made by Harlan, Martini and Stevens (1940). Using barley, 379 crosses were made from 28 varieties which were obtained from all over the world. Crosses were grown for seven generations at Aberdeen, Idaho, in two lots; first, a pedigree lot where each cross was handled separately; and second, a composite lot which was made after mixing equal amounts of seed of the same 379 crosses in the F_2 generation. After seven years of cultivation 5,842 selections were made, 2,921 from each lot. Superiority of the selections made from the composite lot over the selections made from pedigree crosses was observed. Average yield of all the selections from the composite was 480.4 gm as compared to 463.4 gm for pedigree crosses. From pedigree crosses 965 selections were continued; whereas 1,269 selections were saved for further testing from the composite cross.

High correlation between the yields of the pedigree rows before selection and the yields of the selections made in the F_8 generation was found. This relationship was maintained in the yield of the selections tested later.

The study of the pedigree culture showed that crosses between six-rowed and two-rowed were inferior in yield. Out of the 2,921 selections made from the pedigree lot, 1,789 came from six-rowed x six-rowed crosses. Six-rowed segregates were better than two-rowed ones. Awned types were superior to hooded types. Blue aleurone colour was found as a natural character. Naked segregates were less productive than covered ones. On the average, smooth awned types yielded slightly lower than rough awned types although some smooth awned types were as good as rough awned ones. Plants with medium height were better adapted than tall ones.

Immer (1941) found that reduction in yield of the hybrids occurred as the homozygosity increased. Yields of bulk F_2, F_3 and F_4 populations were compared with parents in a replicated trial. Increase in yield over the parental mean in F_2, F_3 and F_4 was 24%, 13% and 5% respectively. This is an 11% reduction in yield as homozygosity increased from 50% in F_2 to 75% in F_3.

Immer (1942) studied the distribution of yields of individual plants of four varieties and four F_2 hybrids of barley. Poor association between the yield of space-seeded parental material and F_2 population was observed. He concluded that the yield of single plants appears to be determined largely by environmental factors.

Taylor (1951) grew a bulk population of 20 barley crosses for one to three years at four locations and concluded that locations at

which segregating generations were grown had a highly significant effect upon subsequent bulk yields. Differences in the maturity and heading date between the composite grown at different locations were also found.

Suneson and Weibe (1942), after growing two different barley varietal mixtures and a mixture of five wheat varieties, suggested that high yield of a variety is not necessarily a criterion of its ability to survive in competition with other varieties grown in mixture. Vaughn barley and Ramona wheat proved to be poor competitors in the mixtures despite their superior adaptability and high yielding capacity. The reasons for the disparity between the yield of an individual variety grown separately and the yield when grown in competition with others are not clearly understood.

Suneson (1949) reported that 16 years of cultivation of a mixture of four barley varieties under natural conditions brought virtual extinction of two of the component varieties. These varieties were Vaughn and Hero, which were considerably more resistant to the leaf diseases and averaged significantly higher in yield than any of the other varieties when tested in pure stands. On the basis of these observations Suneson concluded "the bulk method of breeding would not necessarily perpetuate either the highest yielding or the more resistant progenies but rather those with an intangible character of competitive ability."

Rapid elimination of certain characters in composite populations by natural selection has been demonstrated by Suneson and Stevens (1953). Six different composite crosses of barley were grown for from six to 24 generations at different locations. Characters that showed low survival

in composite populations were (1) two-rowed spike; (2) hooded awns; (3) smooth awns, for which variable survival was observed; and (4) black seeds. At certain stations elimination of black seed was very rapid. Unequal survival of characters at different locations was observed. Continuous improvement was also found in the yield of highly competitive recombinants when grown for long periods.

An evolutionary method of breeding has been suggested by Suneson (1956) which requires the collection and study of seed stock with diverse evolutionary origins, hybridization, the bulking of F_1 progeny and subsequent cultivation of composite crosses under natural conditions. He suggested that 15 generations of natural selection seem desirable. Thereafter material can be subjected to three methods of breeding (1) continued natural selection with prospects for significant gain in yield; (2) cyclic hybrid recombinations with intervening natural selection to give a kind of recurrent selection; or (3) resort to conventional selection testing. Suneson compared four barley composite cross populations with a standard variety, Atlas 46, in successive generations. Early hybrid generations of composite crosses yielded less than the control, but later generations showed a marked yield improvement. Composite cross II and XIV gave higher yield than Atlas 46 in advanced generations.

Sixteen per cent increase in the yield of barley from the F_2 to the F_{16} generation, in C.C.* XIV, has been reported by Suneson and Ramage (1963).

Suneson (1963) reported the superiority of heterozygotes in composite populations. In C.C. II, he found 1.7 and 0.4 per cent of

---

* Composite cross

heterozygosity (on the basis of 2 to 4 characters) in F_{30} and F_{35} generation, respectively. High variability for maturity (April 5 to 25) was also found in F_{35}.

Jain (1961) found a significant linear correlation between fitness and agronomic productivity in a barley bulk population; and he emphasized the significance of the bulk method of barley improvement. Bulk populations provide greater stability in performance under different environmental conditions and under the influence of adverse factors such as in a co-evolving group of pathogenic races. Jain also suggested that as breeding progress under natural selection seems to be slow; artificial selection at a suitable stage might prove effective.

Both directional and stabilizing selection, involving a number of quantitative characters in a composite cross population of barley grown for 18 generations, have been reported by Allard and Jain (1962). Six hybrid generations (F_3, F_5, F_6, F_{13}, F_{15}, and F_{18}) were space seeded in 1958; and observations on heading time, plant height, spike length, spike density and seed size were made, on a single plant basis. No change in the average spike density was observed from F_3 to F_{18}. This constancy of the means of spike density shows that, for this character, stabilizing selection is involved. Directional selection was observed for plant height, spike length, heading time and seed size. The generation means for these characters shifted slowly toward shorter stature, shorter spike, earlier heading and larger seeds. Linear increase in the average population fitness was found with advance in generation. Seeding was also done in 1959 of randomly selected plants from F_3, F_6, F_{13} and F_{18} with 30 parental lines. Larger within-family variance in the F_{19}

generation than in homozygous parental lines indicates that the heterozygotes were having some selective advantage. Allard and Jain suggested that this heterozygosity provides high genetic variability and flexibility which enable the population to respond to changes in environment.

The effect of photoperiod and temperature on the development of spike primoridia in barley has been reported by Johnson and Taylor (1958). Photoperiod was a much more important factor than temperature in determining primordial development. Considerable effect of temperature was observed with 17 hours' exposure to light. Marked difference in the primordial length was found between the 17- and 13-hour photoperiods. Johnson and Taylor concluded, "photoperiod is probably the basic factor determining the expression of earliness in spring barleys, a point which must be taken into account when comparing data from material sown at different times or grown in different latitudes."

Genetic basis of earliness and yield of barley seem to be quite complex and is not clearly understood. To investigate the inheritance of earliness in barley, F_1, F_2 and F_3 of seven crosses of spring barley varieties (early to late types) were studied by Johnson and Paul (1958). Six F_2 phenotypic groups: late, intermediate and early homozygotes, and late, intermediate and early heterozygotes in the ratio 1:2:1:4:4:1 respectively were found. On the basis of this ratio they hypothesized that parents involved in the crosses differed by additive alleles at two loci. Johnson and Paul stated that the hypothesis accounted satisfactorily for the main features of inheritance. Minor discrepancies were attributed to modifying genes, the nature of which could not be determined. Later Johnson and Eunus (1964), on the basis of F_2 data from a six-parent diallel

cross, reported that earliness in barley is a polygenic character and is controlled by both dominant and recessive genes, the contribution of the former being the greater. They also indicated that a total of 17 genes or groups of genes are involved.

Dominance of short sowing-to-heading period over long, and long heading-to-ripening period over short have been reported by Aksel and Johnson (1961). A high degree of association between long seeding-to-heading period and high number of kernels per spike was observed. They found that each character was controlled by different genes. Some evidence for close linkage was also found.

Inheritance of yield in barley was studied by Johnson and Aksel (1959). Biometrical analyses showed that each major component of yield (number of heads per plant, number of kernels per head and weight of kernel) is a polygenic character expression of which is associated with an excess of recessive genes. No significant association was found between the number of heads per plant and the number of kernels per head. Number of kernels per head predominated in determining yield, while kernel weight played a minor role. Johnson and Aksel suggested that similarity in inheritance for yield components may represent different physiologically controlled expressions of the same genes. Grafius (1959) reported that " . . . there are no genes for yield *per se* but only genes for the components of yield. Yield is thus an artifact."

A very comprehensive investigation was carried out by Allard (1961) to determine whether productivity and stability of productivity are related to genetic diversity. Ten lima bean populations representing three levels of genetic diversity (3 pure lines, 4 mixtures of pure

lines and 3 bulk hybrids) were grown for four years at four locations. Four kinds of comparisons were made, which were: (a) all pure lines vs. all mixtures and all bulks; (b) each mixture vs. the pure lines from which it was synthesized; (c) each bulk hybrid vs. its parents; and (d) mixtures vs. bulks derived from the same pure lines. Order of the productivity and stability of productivity was bulks $>$ pure lines $>$ mixtures and bulks $\geq$ mixtures $>$ pure lines, respectively. Genetically uniform populations, i.e., pure lines, were highly successful in some environments and inefficient in others. However, bulks and mixtures, on the average, gave good performance at all locations indicating that genetically diverse populations were often stable in any one environment. Allard stated that "the superiority of complex hybrid over simple mixtures was associated not with heterosis but with the ability of different genotypes to exploit particular ecological sites to their own particular advantage."

Competitive ability of F_1 hybrids in barley was studied by Sakai and Gotoh (1955). On the average the competitive ability of F_1 hybrids was found to be inferior to that of the average performance of their parents, despite their vigorous growth due to heterosis. Sakai and Gotoh concluded, "competitive ability should be accepted as a plant character quite independent from hybrid vigour." Sakai (1955) found that diploid plants were always good competitors against the autotetraploids, for all the characters studied. Difference in the competitive ability of an autotetraploid was observed when it was mixed with different diploid testers. It shows the importance of genotype in the competitive ability of a particular line. Allopolyploids were found to be superior to their weaker progenitors. Smith (1960) reported that

fertility of induced autotetraploids of barley was lower than diploids. He also found that two-rowed autotetraploids were more fertile than six-rowed ones.

Anderson (1939) on the basis of his work on interspecific hybridization in Nicotiana stated that recombination of quantitative characters in crosses between species and races is limited in the second generation to a relatively small fraction of the total potential recombinations. The factors such as (a) gametic elimination, (b) zygotic elimination, (c) pleiotropism and (d) linkage were found to be operating to hinder recombination.

Hanson (1959a) has derived the probability distribution for the length of parental gene block remaining intact through the meiotic cycle. The mathematical model presented provides the basis for the evaluation of the extent to which the original linkage groups from a parent are broken under selected breeding procedures. Later Hanson (1959b), on the basis of his mathematical model developed for the probability of linkage break up, suggested that in a self-pollinated species intermating cycles (at least one or more) should precede the selfing generations to insure a degree of breakup of the linkage groups and to increase the genetic recombinations within the linkage group. Hanson emphasized that four or more parents should be included in the intermating population to increase the genetic potentials of the population.

Barley is classified as a naturally self-fertilized crop although some out-crossing has been reported by several workers. Ueki (1952), as cited by Nilan (1964), found 0.061 per cent cross fertilization

in some mixed-seeded barley varieties. On the other hand, no natural crossing was found when varieties were grown in alternate rows. Jain and Allard (1960) found one to two per cent outcrossing in barley. Suneson (1953) reported that, in barley, frost at heading time may cause natural crossing to a large extent. In one year, 16 of 19 plants of hybrid origin were found in variety Atsel which was exposed to frost at anthesis.

All the cultivated species of barley are diploid; several diploid and polyploid wild species are known (Nilan, 1964). The origin, phylogeny, taxonomy and genetics of barley are discussed by Nilan (1964), Takahasi (1963), Bakhteyev (1963), Wiebe and Reid (1961), Leonard and Martin (1963), etc. It is known that some of the qualitative characters, e.g., spike type, type of awn and color of pericarp in barley are controlled by single genes (Murty and Jain, 1959, 1960; Litzenberger and Green, 1951; etc.). Two-row, rough awn and black pericarp are dominant over six-row, smooth awn and non-black pericarp, respectively. Evidence also exists for involvement of more than one gene.

Variability in crop plants, its use and "gene conservation" are very well described by Simmonds (1962).

MATERIALS AND METHODS

This research project was initiated by Prof. L.P.V. Johnson in 1955 when the fifteen barley varieties listed in Table 1, were crossed in all possible combinations, excluding reciprocals, resulting in a total of 105 crosses (Johnson and Aksel, 1959). Parental varieties were chosen to provide genotypes differing in yield, earliness, height, etc.

Table 1. Barley varieties involved in the composite cross.

No.	Varieties	Genotypes*	No.	Varieties	Genotypes
1	Beecher	vv bb RR	9	Plains	vv bb rr
2	Fjola	vv bb RR	10	Proctor	VV bb RR
3	Hannchen	VV bb RR	11	Sanalta	VV bb rr
4	Herta	VV bb RR	12	Titan	vv bb rr
5	Husky	vv bb rr	13	Trebi	vv bb RR
6	Jet	VV BB RR	14	Vantage	vv bb rr
7	O.A.C. 21	vv bb RR	15	Velvon 11	vv bb rr
8	Peatland	vv bb RR			

* vv - 6-rowed, VV - 2-rowed, bb - nonblack seed, BB - black seed, rr - smooth awn, RR - rough awn.

The hybrid seeds of F_1 to F_3 generations were grown in Edmonton at Parkland Farm, University of Alberta. After harvest of the F_3 generation, the seed of the 105 crosses, in equal parts by weight, were mixed together to form the composite. An eight-pound sample of seed of this composite was supplied to each station listed in Table 2. These stations are located over a wide range of latitudes. Approximate locations of all stations except Vollebekk (Norway) are shown in Fig. 1

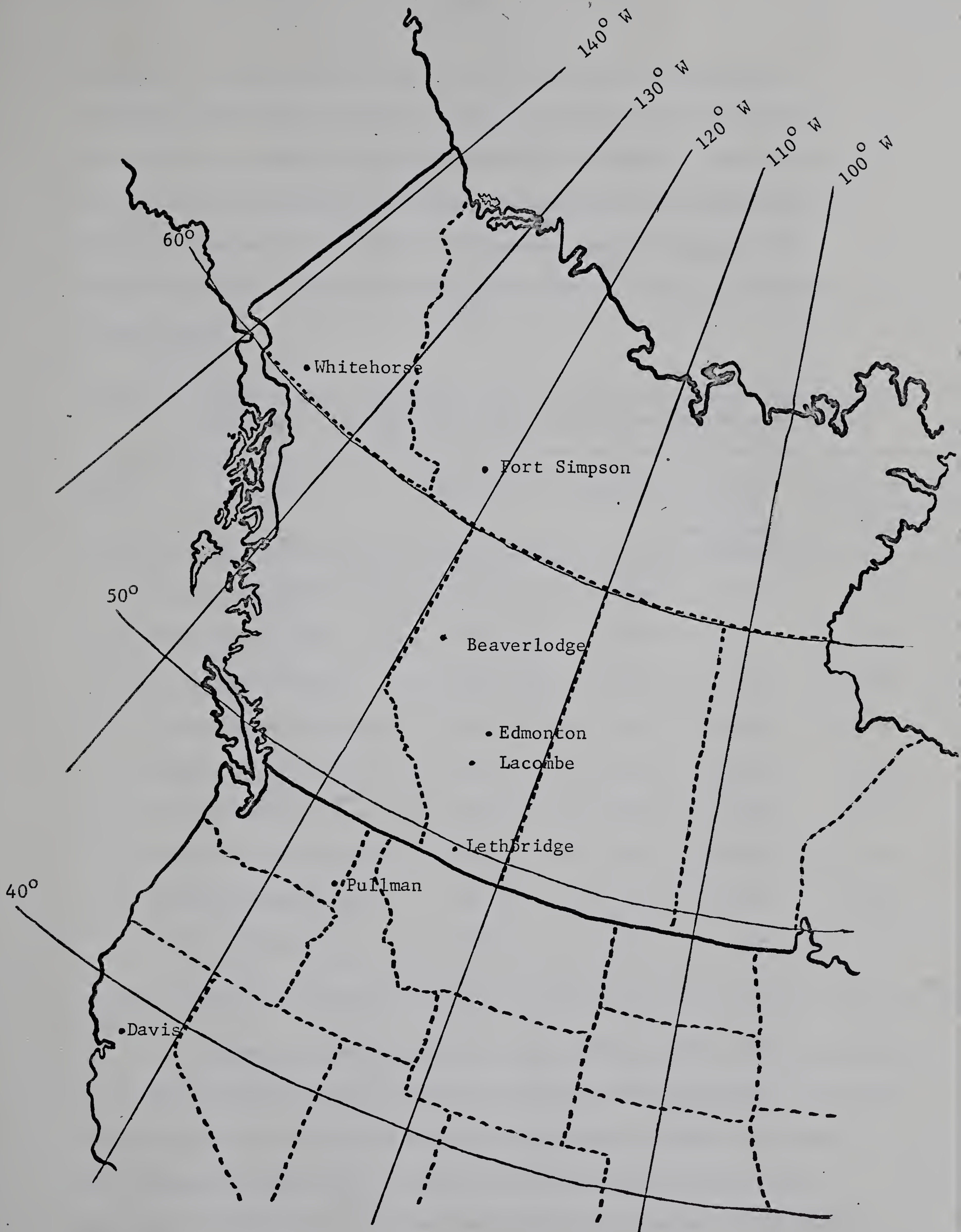


Figure 1. Approximate location of the stations.

(page 15). The latitude, longitude, altitude and average annual precipitation of each Canadian station was obtained from the Monthly Record, Meteorological Branch, Department of Transport. For stations in the U.S.A. and Norway the values were obtained from Climatology of United States No. 60, U.S. Dept. of Commerce, Weather Bureau; and Climate and Man, Yearbook of Agriculture 1941, U.S. Dept. of Agriculture, respectively.

Table 2. Stations where composite cross of barley was grown, with latitude, longitude, altitude and average annual precipitation of each.

Code no.	Station	Latitude N °	'	Longitude °	'	Altitude above sea level in ft.	Average annual precipitation in inches
1	Fort Simpson (N.W. Terr.)	61	52	121	21W	430	13.58
2	Whitehorse (Yukon Terr.)	60	43	135	04W	2,289	9.51
3	Vollebekk (Norway)	59	55	10	43E	82	23.21
4	Beaverlodge (Alberta)	55	11	119	22W	2,500	18.30
5	Edmonton (Alberta)	53	34	113	31W	2,219	18.64
6	Lacombe (Alberta)	52	28	113	45W	2,783	18.17
7	Lethbridge (Alberta)	49	43	112	51W	2,961	17.56
8	Pullman (Washington)	46	46	117	09W	2,350	19.45
9	Davis (California)	38	32	121	45W	60	16.43

The bulk composite cross of barley was grown for five generations, F_4 to F_8 inclusive, under conditions of strong competition at all stations. The procedure of cultivation at all stations was the same, the mixture was seeded, at a high rate, in field plots each year, the plots were harvested, threshed and a random sample of seed was saved sufficient to

sow a plot in the following year. After five years of cultivation a sample of resulting seed (10 lb) was obtained from each station. For comparisons between these naturally-selected materials and the unselected original stock (F_3 held in reserve storage), the recovered samples were grown and studied by the author in three different tests at Parkland Farm, University of Alberta, in 1964 and 1965.

1. Bulk Hybrid Test

In 1964 the final year's seed from all stations, together with original unselected F_3 bulk seed were sown in plots of four rod-rows in 20 replications. Sowing was done by power seeder at a rate of 1,000 seeds per plot. A second seeding was made a week after the first. Most of the seed obtained from Whitehorse had been damaged by frost which made valid observations impossible in 1964. The seed harvested from the 1964 crop (F_9) was used for seeding in 1965. In 1965 the variety Husky was also included in the test and the materials were seeded in plots of eight rod-rows each by power seeder in a balanced incomplete block design (six replications). Heavy rainfall and high winds caused much lodging in plots of the second seeding in 1965; therefore, only yield notes were taken from them.

Notes on heading dates were taken as the number of days from seeding until about 90 per cent of the plants in a plot were headed. Similarly, maturity dates were taken as the number of days from seeding until about 90 per cent of the heads in a plot were matured. Average height of plant in each plot was taken in cm from ground to the tip of the head, based on three random observations. For determining yield per plot in 1964 the central two rows, and in 1965 the central six rows

of 16-1/2 feet each were harvested, leaving the outer two rows as plot border. Threshing was done by power thresher. Threshed seed was weighed to nearest gram. A random sample of a thousand kernels (counted by hand) was taken from the seed of each station and weighed to 0.05 gm accuracy by electric balance especially designed for the purpose. The number of black kernels were counted in a sample of 200 gm of seed for determining their proportion in the seed of each station, expressed as a percentage. The number of kernels in 200 gm of seed were estimated on the basis of thousand kernel weight. Observed number of black kernels was compared with that of the expected. The expected proportion of black kernels was calculated on the assumption of a dominant monogenic inheritance of black kernel assuming no selection pressure against or in favour of the character (Appendix VIII).

2. Spaced-Plant Test

For detailed studies of morphological and quantitative (polygenic) characters, one plot of about 400 plants from the seed of each station was sown by space seeder in 1964 and 1965. In each plot, a random sample of 200 plants was tagged and analyzed for the following characters:

1. Heading date,
2. Two vs. six rowed,
3. Rough vs. smooth awn,
4. Shape of basal rachis internode (short-curved, short-straight, long-curved, or long-straight)
5. Collar type (closed, open or V-shaped),
6. Neck length (short, medium or long),
7. Neck shape (straight, curved or snaky),

8. Leaf width (narrow, medium or broad),
9. Height of the plant in cm,
10. Number of heads per plant,
11. Yield per plant in gm.

These characters were selected primarily because they occurred as easily recongizable types in the populations. Some neutral forms such as awn and collar types were considered as markers having possible linkage with adaptive characters.

3. Progressive Generation Test

From some stations, reserve seeds of successive generations were also available for final comparative tests as shown in Table 3. In 1964 samples of such seeds, shown in Table 3, were sown in a randomized block design in four rod-row plots using three replications, Sowing was done by power seeder at the rate of 1,000 seeds per plot.

Table 3. Samples of composite cross of barley available (+) for progressive generation test.

Station	F_3 control	F_4	F_5	F_6	F_7	F_8
Edmonton	+	+	+	+	+	+
Beaverlodge		+		+	+	+
Whitehorse			+	+	+	+
Fort Simpson			+			+
Davis				+		+

Two central rows of each plot were harvested for yield determinations. After threshing, seed was saved for seeding the

following year. In 1965 these 18 samples were grown in four rod-row plots in five replications. Observations on heading date, maturity, height, yield, thousand kernel weight and proportion of black kernels were taken as described for bulk hybrid test. Notes on maturity and height were not taken in 1965 because of too much lodging.

4. Statistical Analyses

Methods outlined by Johnson (1963) and Cochran and Cox (1957) were used in the analyses. The significance of difference between the means, where analyses of variance showed significant mean squares, was tested by Duncan's (1955) multiple range test. In underscoring, instead of name of stations, code numbers (given in Table 2) have been used for convenience. Any two stations underscored by the same line are not significantly different. On the other hand, any two stations not underscored by the same line are significantly different ($P < 0.05$).

The analyses of variance, where data were taken on per cent bases, were calculated after the angular transformation. Regression co-efficients were calculated for the thousand kernel weight to find out whether there has been natural selection for or against kernel weight. In progressive generation test percentage of certain characters were calculated in the samples of Edmonton (F_5 to F_9) as compared to the control (F_4) to see the trend of these traits in successive generations. For other stations it was not possible due to the lack of successive generation samples. Since the seed from Whitehorse was badly frozen, analyses of the observations taken in 1964 are not valid for this material.

EXPERIMENTAL RESULTS

Experimental results are presented in three sections namely, Bulk hybrid test, Spaced-plant test and Progressive generation test.

1. Bulk Hybrid Test

Heading date

The average number of days from seeding to heading for the samples of all stations with their ranks from early to late, for 1964 and 1965, is given in Table 4. The t values of all possible comparisons for both seedings of 1964 are given in Appendices I and II. In 1964, samples obtained from Beaverlodge, Edmonton, Lacombe, Pullman, Lethbridge and Vollebekk headed significantly ($P < 0.05$) later than the control. No significant differences were observed between the heading period of the control and the samples obtained from Whitehorse, Fort Simpson and Davis. In the second seeding (1964) the control headed significantly ($P < 0.01$) earlier than the samples of Whitehorse and Fort Simpson, although no difference was observed in the first seeding.

The analysis of variance for days to heading in 1965 is given in Table 5. The very high value of station variance indicates significant ($P < 0.01$) differences among the results of the samples obtained from various stations for heading period. Figures 2 to 9 (pages 24 to 27) show relative degree of heading of all samples 53 days after seeding in 1965.

Table 4. Average number of days from seeding to heading of barley for samples from all stations, with ranking from early to late, grown in 1964 and 1965.

Code no.	Station (with control and standard)	1964 (F_9) First seeding Days to head	Rank	1964 (F_9) Second seeding Days to head	Rank	1965 (F_{10}) Days to head	Rank
1	Fort Simpson	59.6 ± .51	3	57.0 ± .54	4	60.8 ± .56	2
2	Whitehorse	60.1 ± .31	4	56.1 ± .57	3	57.0 ± .00	1
3	Vollebekk	61.6 ± .45	7	57.9 ± .54	5	66.0 ± .74	8
4	Beaverlodge	64.4 ± .46	10	60.4 ± .55	10	66.7 ± .65	10
5	Edmonton	62.0 ± .27	8	58.5 ± .43	8	66.8 ± .74	11
6	Lacombe	62.0 ± .44	9	59.2 ± .54	9	66.1 ± .75	9
7	Lethbridge	61.4 ± .45	6	58.4 ± .43	7	65.0 ±1.00	7
8	Pullman	60.8 ± .30	5	58.0 ± .56	6	63.4 ± .88	5
9	Davis	58.2 ± .34	1	54.2 ± .49	2	62.1 ± .98	4
10	Control	59.4 ± .58	2	54.0 ± .47	1	64.2 ±1.12	6
11	Husky variety	-		-		61.8 ± .56	3
-	Mean	61.0		57.4		63.6	

Table 5. Analysis of variance for the average number of days from seeding to heading of barley grown in 1965.

Source of variation	D.F.	M.S.	F calculated	Table value of F 5%	1%
Station	10	54.75	31.10**	2.05	2.75
Block	10	13.83	8.59**	2.05	2.75
Intrablock error	45	1.76			
Total	65				

2 1 11 9 8 10 7 3 6 4 5

In 1965, samples of Whitehorse, Fort Simpson and Davis headed significantly ($P < 0.05$) earlier than the control, as shown in Figures 2, 3 and 7. Variety Husky also headed earlier than the control. Samples obtained from Beaverlodge, Edmonton, Lacombe and Vollebekk headed significantly ($P < 0.05$) later than the control, shown in Figures 3, 4, 5 and 8. The control and the samples from Pullman and Lethbridge headed at nearly the same time. No significant differences were observed among the heading periods of samples of Beaverlodge, Edmonton, Lacombe, Vollebekk and Lethbridge; of Fort Simpson, Davis and variety Husky; and of Lethbridge and Pullman.

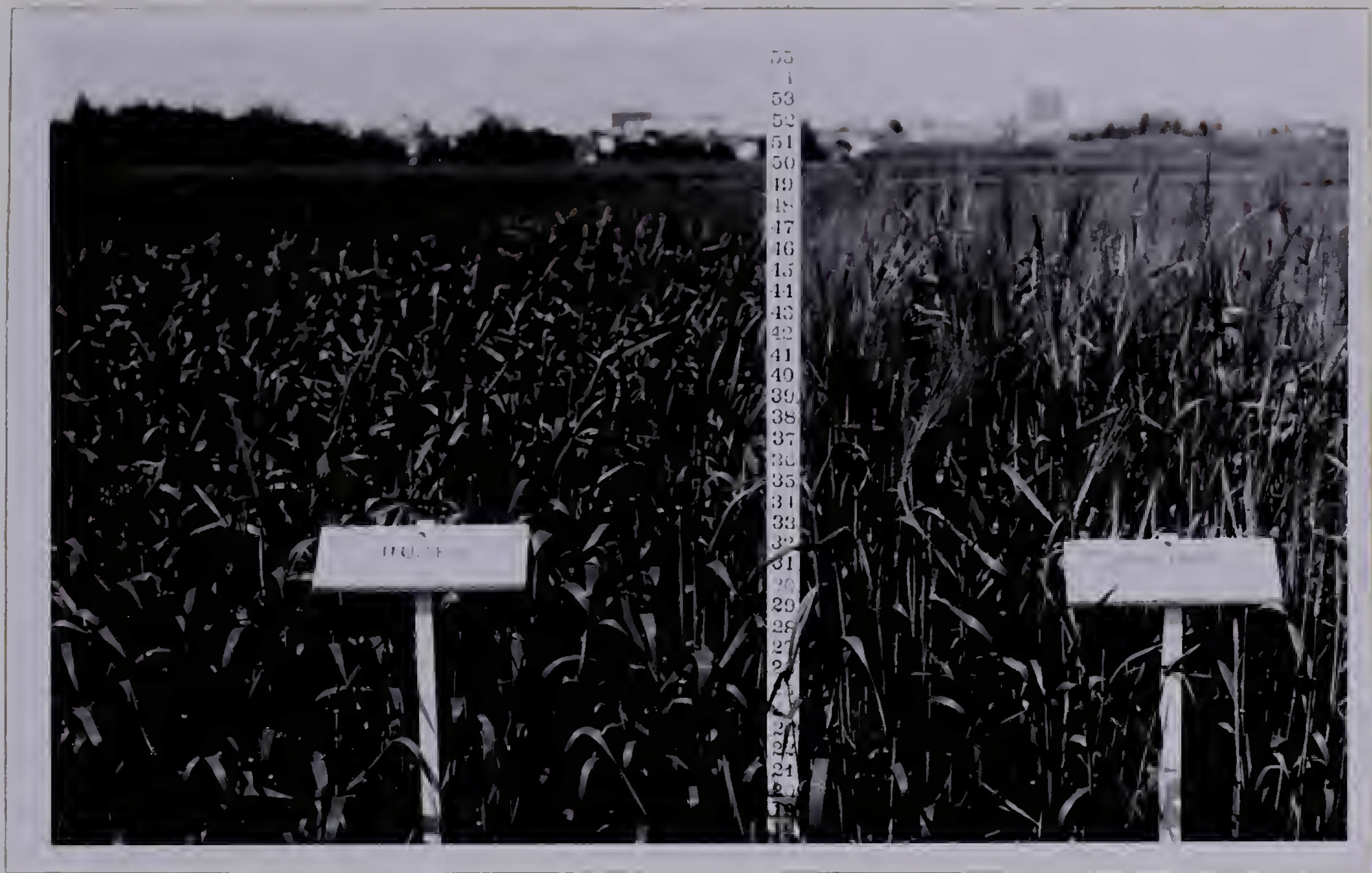


Figure 2. Heading stage of variety Husky and Whitehorse (L. to R.) materials 53 days after seeding in 1965.

Figure 3. Heading stage of Fort Simpson and Beaverlodge (L. to R.) materials 53 days after seeding in 1965.

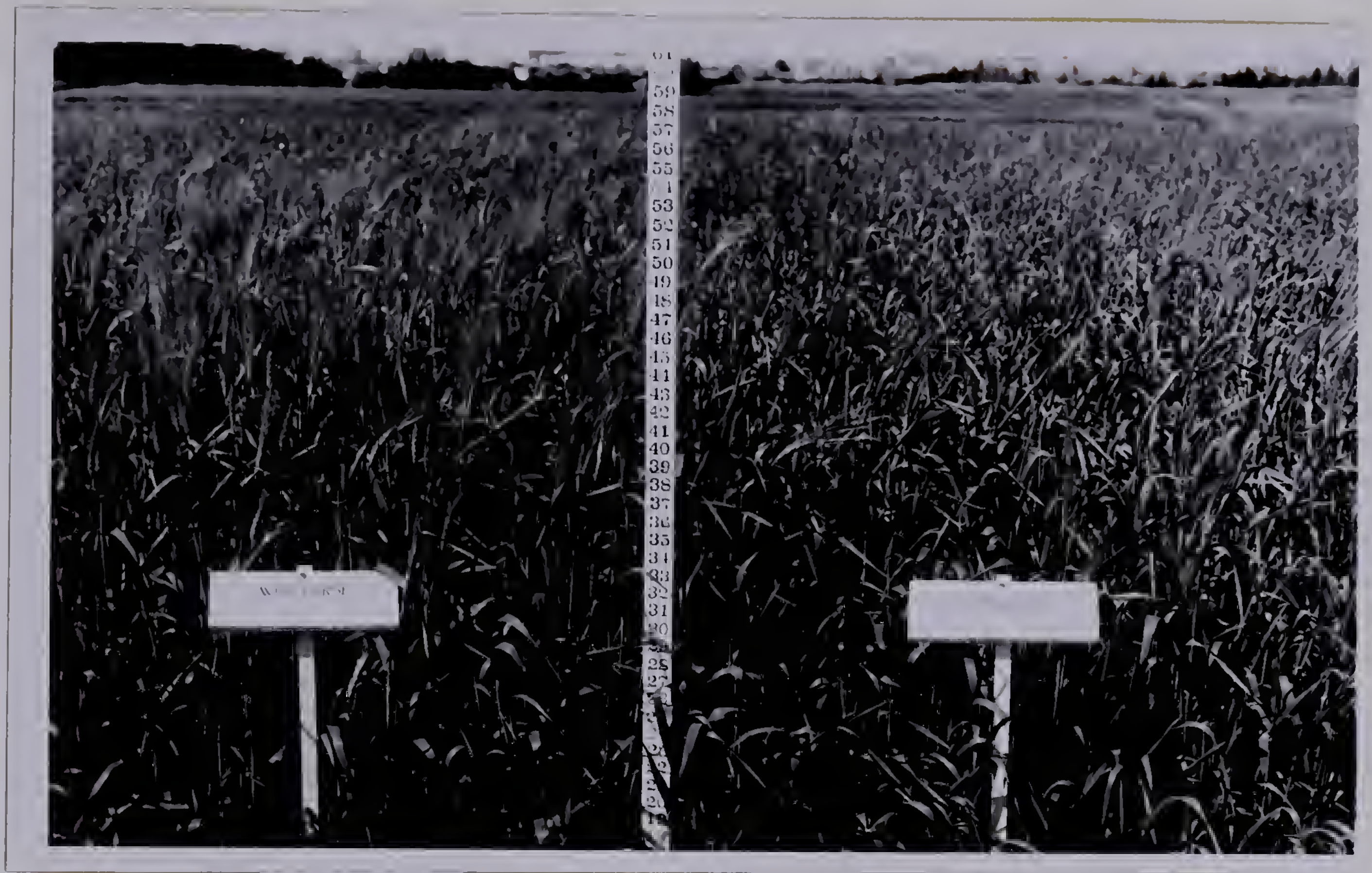


Figure 4. Heading stage of Whitehorse and Edmonton (L. to R.) materials 53 days after seeding in 1965.

Figure 5. Heading stage of Lacombe and Pullman (L. to R.) materials 53 days after seeding in 1965.

Figure 6. Heading stage of Lethbridge and Davis (L. to R.) materials 53 days after seeding in 1965.

Figure 7. Heading stage of Beaverlodge and Davis (L. to R.) materials 53 days after seeding in 1965.

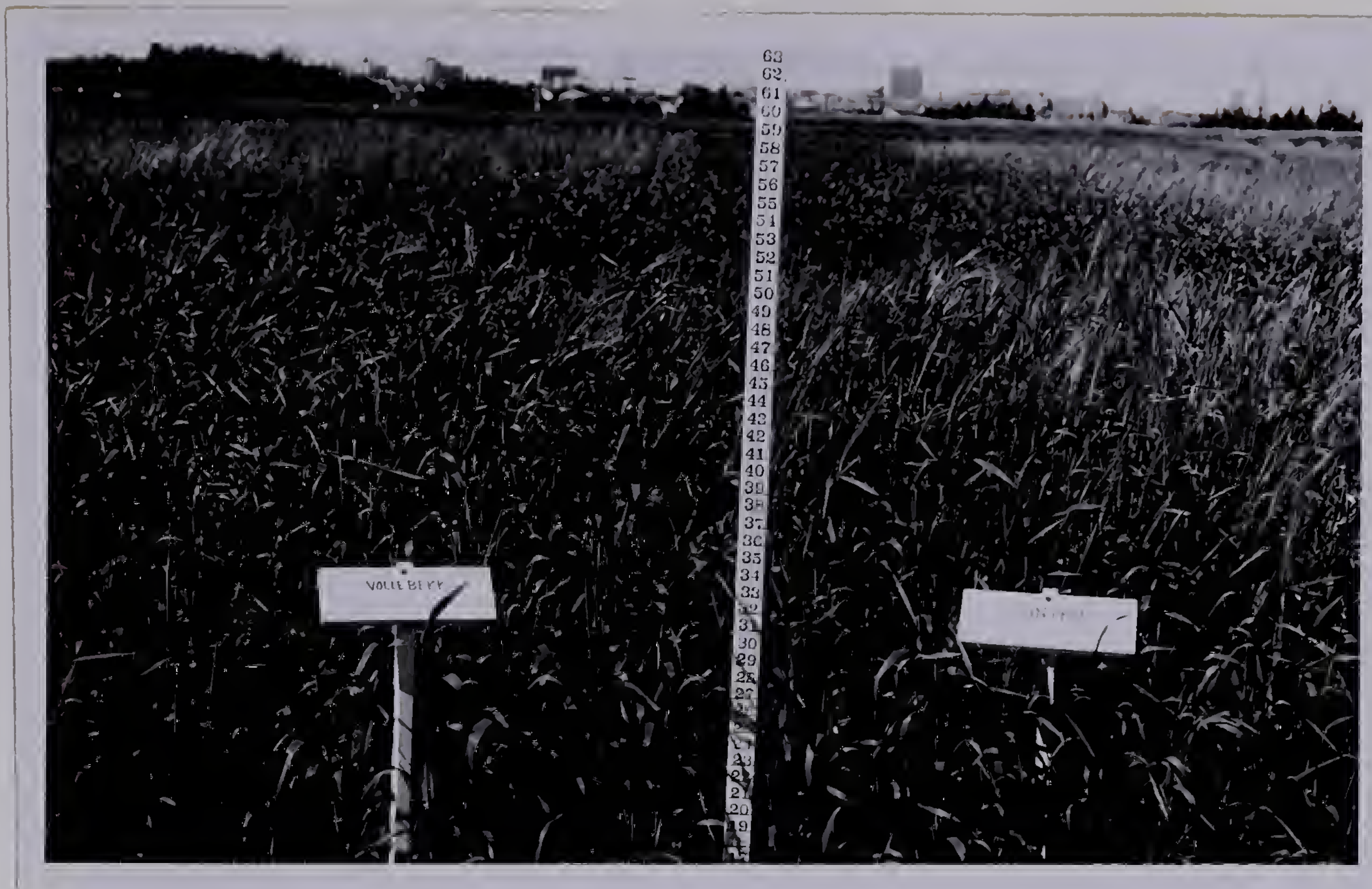


Figure 8. Heading stage of Vollebekk and control (L. to R.) materials 53 days after seeding in 1965.

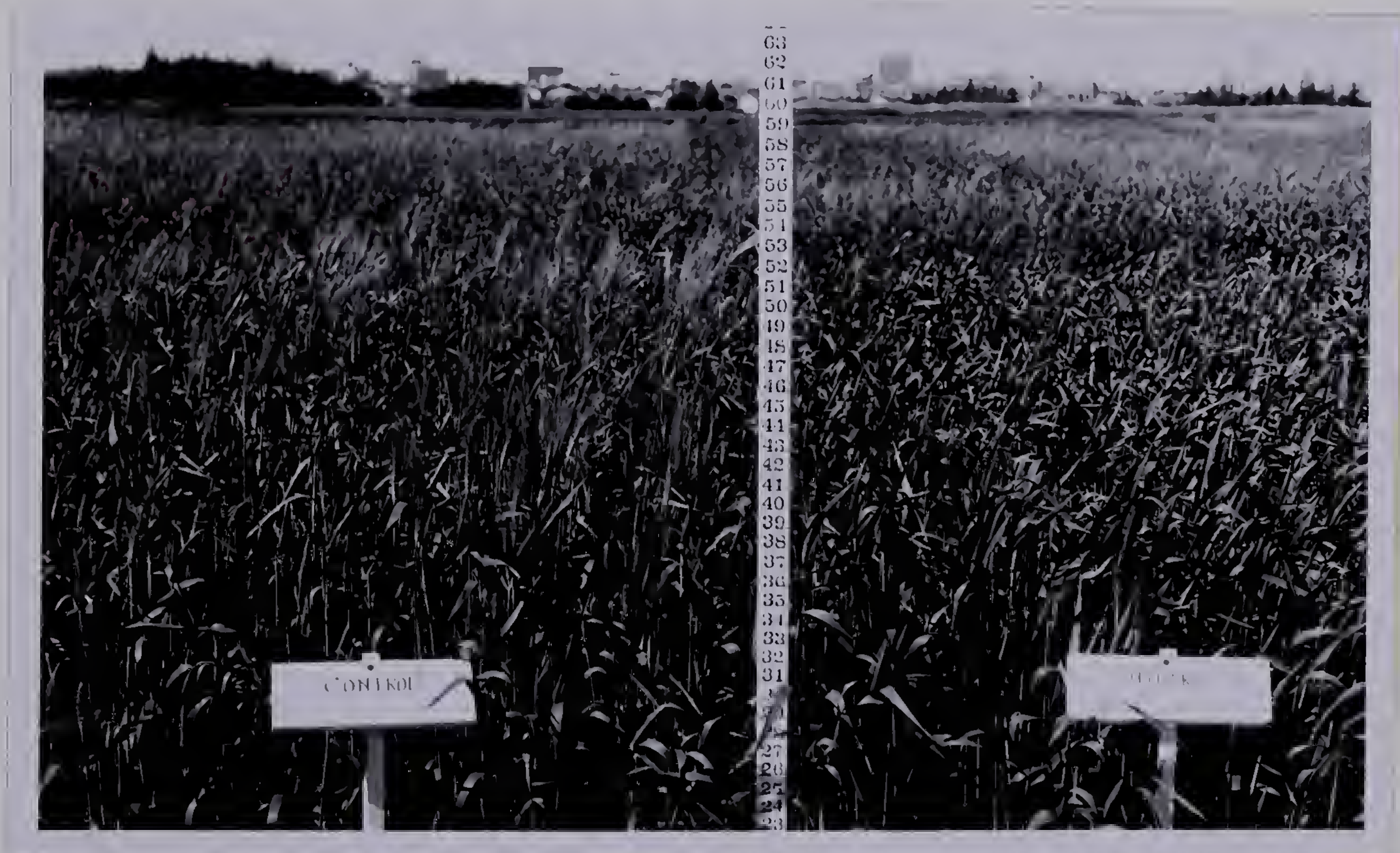


Figure 9. Heading stage of control and variety Husky (L. to R.) 53 days after seeding in 1965.

Height of the plant

Average plant height in cm for samples from all stations with their ranks (shorter to taller) is given in Table 6. The t values of all possible comparisons on the bases of 1964 observation is given in Appendix III.

Table 6. Average height of barley plants for samples from all stations, with ranking from short to tall, grown in 1964 and 1965.

Code no.	Station (with control and standard)	1964 (F_9) Height, cm	1964 (F_9) Rank	1965 (F_{10}) Height, cm	1965 (F_{10}) Rank
1	Fort Simpson	86.3 ± 1.17	5	109.5 ± 2.29	9
2	Whitehorse	79.3 ± 1.06	1	103.6 ± 1.70	1
3	Vollebekk	87.8 ± 1.17	6	109.7 ± 2.17	10
4	Beaverlodge	88.7 ± 1.54	7	109.4 ± 1.30	8
5	Edmonton	91.1 ± 1.23	9	109.3 ± 1.82	7
6	Lacombe	92.7 ± 1.37	10	112.4 ± 1.33	11
7	Lethbridge	90.4 ± 1.07	8	108.9 ± 2.77	6
8	Pullman	83.3 ± 1.22	3	108.8 ± 0.56	5
9	Davis	81.8 ± 1.10	2	105.6 ± 1.77	2
10	Control	84.3 ± 0.99	4	108.2 ± 2.36	3
11	Husky variety	-	-	108.3 ± 1.97	4
-	Mean	86.6		108.5	

In 1964, the average plant height of the samples obtained from Whitehorse was significantly ($P < 0.05$) shorter than the averages of other samples except that of Davis. Plant height of the sample from Davis was second shortest and was significantly ($P < 0.05$) shorter than

the samples from Fort Simpson, Beaverlodge, Edmonton, Lacombe, Lethbridge and Vollebekk. The plant-height averages of the samples obtained from Lacombe, Lethbridge, Edmonton and Beaverlodge were significantly taller than the control. No difference was observed between the results of the control and of the samples obtained from Fort Simpson, Pullman and Davis for plant height.

In 1965 station variance for average plant height was found non-significant, indicating no significant differences among the results of samples obtained from various stations for plant height. Despite the non-significant station variance in 1965 the range and rank for the average plant height of the samples were similar to those of 1964.

Maturity date

Average number of days from seeding to maturity for the samples from various stations with their ranks from early to late is given in Table 7. Table 8 shows the analysis of variance for average number of days from seeding to maturity in 1965. The t values for all possible comparisons, based on 1964 observations, are given in Appendix IV.

In 1964, no difference in maturity was observed between the results of the control and of the samples obtained from Fort Simpson and Lethbridge. Samples from Whitehorse, Beaverlodge, Edmonton, Lethbridge, Pullman, Davis and Vollebekk also matured at nearly the same time. The sample from Lacombe was last to mature and was significantly ($P < 0.05$) later than the samples of Fort Simpson, Edmonton, Lethbridge, Pullman and control. Whitehorse ranked in ninth position in maturity in 1964 and first in 1965. This disparity is due to poor germination from frozen seed (harvested in Whitehorse) in 1964.

Table 7. Average number of days from seeding to maturity of barley for samples from all stations, with ranking from early to late, grown in 1964 and 1965.

Code no.	Station (with control and standard)	1964 (F_9) Days to mature	1964 (F_9) Rank	1965 (F_{10}) Days to mature	1965 (F_{10}) Rank
1	Fort Simpson	104.5 ± .71	1	96.5 ± .59	2
2	Whitehorse	110.7 ± .59	9/	93.8 ± .44	1
3	Vollebekk	108.6 ± .93	5	99.1 ± .81	5
4	Beaverlodge	110.5 ± .80	8	100.7 ± .52	9
5	Edmonton	108.3 ± .60	4	100.1 ± .55	6
6	Lacombe	111.4 ± .87	10	101.1 ± .60	10
7	Lethbridge	107.4 ± .89	3	100.5 ± .99	7
8	Pullman	108.9 ± .83	6	101.6 ± .65	11
9	Davis	109.5 ± .70	7	100.6 ± .87	8
10	Control	105.5 ± .87	2	98.9 ± .95	4
11	Husky variety	-	-	98.7 ± .44	3
-	Mean	108.5		99.2	

/ Sparse stand due to poor germination, producing late plants.

Table 8. Analysis of variance for the average number of days from seeding to maturity of barley grown in 1965.

Source of variation	D.F.	M.S.	F calculated	Table value of F 5%	Table value of F 1%
Station	10	31.92	21.37**	2.05	2.75
Block	10	9.79	7.09**	2.05	2.75
Intrablock error	45	1.49			
Total	65				

2 1 11 10 3 5 7 9 4 6 8

Order of maturity of all samples in 1965, with few exceptions, was similar to that of 1964. Samples from Whitehorse and Fort Simpson matured significantly ($P < 0.05$) earlier, and those from Beaverlodge, Lacombe, Lethbridge, Pullman and Davis matured significantly ($P < 0.05$) later than the control. No significant differences were found among the results of the samples of Beaverlodge, Edmonton, Lacombe, Lethbridge, Pullman and Davis for maturity period. The control and the samples from Edmonton and Vollebekk and variety Husky matured at nearly the same time.

Yield per plot

Average seed yield per plot in gm for samples from all stations grown in 1964 and 1965 is given in Table 9. The t values of all possible comparisons, based on 1964 observations, are given in Appendices V and VI, and the analysis of variance of 1965 observation is given in Table 10.

The samples obtained from Beaverlodge, Edmonton, Lacombe, Lethbridge, Pullman and Davis yielded significantly ($P < 0.05$) higher than the control in both seedings of 1964. No significant difference was observed among the yields of the control and of the samples obtained from Fort Simpson and Vollebekk. Yield of the sample from Fort Simpson was also not significantly different from those of Davis and Pullman. The sample from Whitehorse gave the lowest yield. The four highest yielding samples in 1964 were Beaverlodge, Lethbridge, Lacombe and Edmonton.

In 1965 station variance of first seeding (Table 10) was found to be highly significant ($P < 0.01$), which indicates significant differences among the results of the samples from various stations for the average yield per plot. The samples which gave significantly higher

Table 9. Average seed yield per plot of barley for samples from all stations, with ranking from high to low, grown in 1964 and 1965.

Code no.	Station (with control and standard)	1964 (F_9) First seeding Yield, gm	Rank	1964 (F_9) Second seeding Yield, gm	Rank	1965 (F_{10}) First seeding Yield, gm	Rank	1965 (F_{10}) Second seeding Yield, gm	Rank
1	Fort Simpson	734 ± 13	7	717 ± 13	8	2596 ± 34	9	2446 ± 54	8
2	Whitehorse	487 ± 27	10	583 ± 16	10	2638 ± 51	7	2483 ± 78	6
3	Vollebekk	708 ± 14	8	724 ± 10	7	2579 ± 92	11	2434 ± 72	9
4	Beaverlodge	808 ± 16	2	791 ± 13	1	2858 ± 59	2	2431 ± 153	11
5	Edmonton	792 ± 15	4	772 ± 10	3	2633 ± 42	8	2472 ± 110	7
6	Lacombe	794 ± 14	3	784 ± 12	2	2671 ± 57	6	2680 ± 119	1
7	Lethbridge	819 ± 17	1	760 ± 13	4	2880 ± 84	1	2542 ± 138	4
8	Pullman	744 ± 11	6	739 ± 13	6	2806 ± 110	3	2553 ± 291	3
9	Davis	773 ± 15	5	751 ± 14	5	2792 ± 81	4	2637 ± 134	2
10	Control	704 ± 11	9	696 ± 10	9	2592 ± 108	10	2433 ± 53	10
11	Husky variety	-	-	-	-	2759 ± 81	5	2505 ± 102	5
-	Mean (per rod-row)	368		366		452		419	

Note: Plots in 1964 were of two rod-rows and in 1965 of six rod-rows.

Table 10. Analysis of variance for the average yield of barley per plot (six rod-rows) in gm for both seedings of 1965.

Source of variation	D.F.	First seeding M.S.	First seeding F calculated	Table value of F 5%	Table value of F 1%	Second seeding M.S.	Second seeding F calculated	Table value of F 5%	Table value of F 1%
Station	10	76,692.6	3.14**	2.05	2.75	43,222.4	0.93	2.65	4.15
Block	10	95,871.8	4.20**	2.05	2.75	204,269.1	4.72**	2.05	2.75
Intra block error	45	24,428.4				43,362.6			
Total	65								

3 10 1 5 2 6 11 9 8 4 7

yield than the control were from Lethbridge, Beaverlodge, Pullman and Davis and as a group their average yields were not significantly different. No significant differences were observed among the yields of the samples obtained from Whitehorse, Fort Simpson, Edmonton, Lacombe, Vollebekk and the control. Average yield of variety Husky was also not different from the control. No significant differences were observed among the results of the samples from various stations in the second seeding (Table 10). Despite the non-significant differences among the results of different samples in the second seeding of 1965, order of yields (ranks), with few exceptions, was similar to that of other seedings.

On the average (over 1964 and 1965) the high yielding types were the samples from Lethbridge, Davis, Lacombe, Beaverlodge and Pullman. The Beaverlodge sample, because of being a later type, suffered most from the lodging and gave the lowest yield in the second seeding of 1965. The control ranked next to last in both years.

Proportion of black kernels

The percentages of black kernels in samples of all stations are shown in Figures 12 and 13 (pages 55 and 56) with expected percentages of black kernels. In the original bulk (control F_3) percentage of black kernels was 7.42, but none of the final year's (F_{10}) samples contained more than one per cent of black kernels except the sample from Whitehorse in which 3.3 per cent black kernels were found. Expected percentage of black kernels in the F_{10} generation of all treatments was 6.68 assuming no selection pressure against or in favour of the character.

Thousand kernel weight

The average thousand kernel weight in gm for samples of all stations, based on one to three years of observation, is given in Table 26 (page 57). In the final generation (F_{10}) samples of all stations, thousand kernel weight was lower than the control. On the average, very little differences were observed among the results of the samples obtained from different stations. Thousand kernel weight of samples from Fort Simpson was the lowest (33.67 gm) and that from Davis the highest (38.67 gm) in F_{10}.

2. Spaced-Plant Test

The summary of all observations taken on spaced seeded material is given in Appendix VII.

Spike type

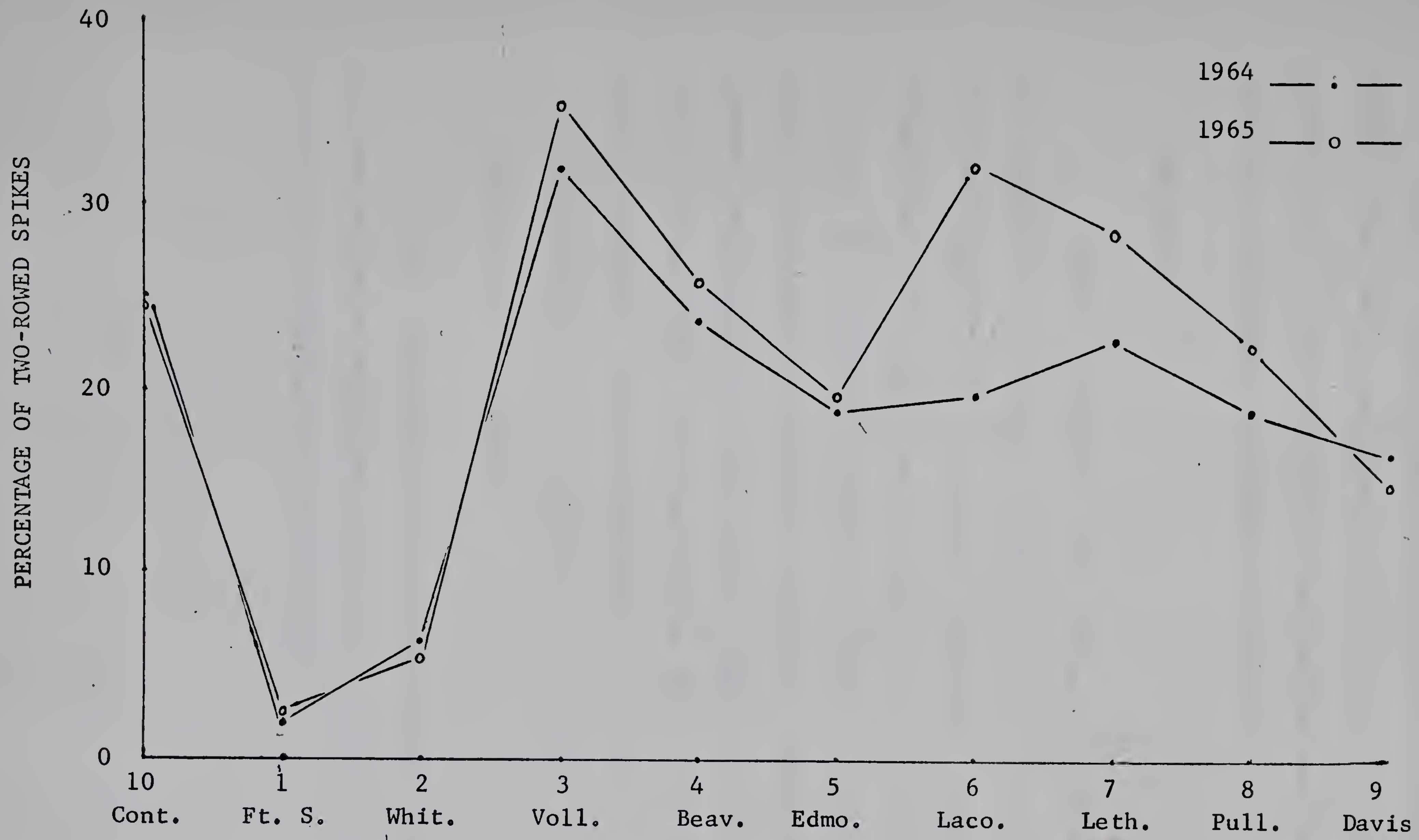
The proportion of two- and six-rowed spikes in F_9 and F_{10} generations of all samples were calculated to determine whether there had been natural selection in favour or against any particular spike type. The analysis of variance is given in Table 11. The station variance was found highly significant ($P < 0.01$), which indicates significant differences among the results of the samples from different stations. No significant yearly difference was observed in spike type. Figure 10 (page 36) shows percentages of the two-rowed spikes in the samples from all stations in 1964 and 1965.

Table 11. Analysis of variance for the average percentage of two-rowed spikes of barley grown in 1964 and 1965.

Source of variation	D.F.	M.S.	F calculated	Table value of F	
				5%	1%
Station	9	137.74	34.18**	3.18	5.35
Year	1	14.58	3.62	5.12	10.56
Error	9	4.03			
Total	19				

1 2 9 5 8 10 4 7 6 3

Comparisons of means show that there were no significant differences for spike types between the composition of the control sample and of the samples obtained from Beaverlodge, Lethbridge, Lacombe and Pullman. In all other samples the proportion of two-rowed spikes had considerably decreased, except in the sample from Vollebekk



1 = Fort Simpson
2 = Whitehorse
3 = Vollebekk
5 = Edmonton
6 = Lacombe
7 = Lethbridge
8 = Pullman
9 = Davis
10 = Control

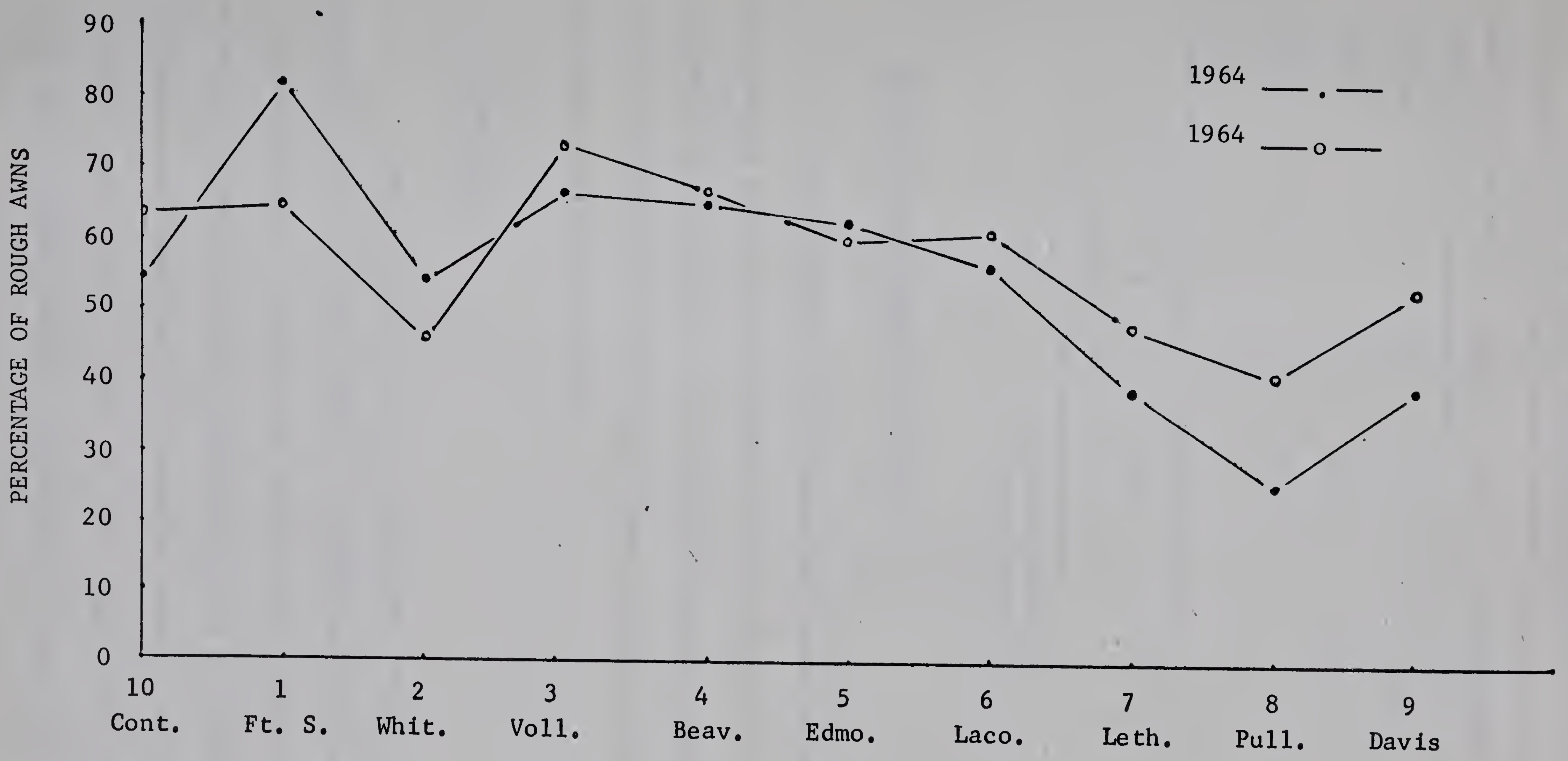
Figure 10. Percentage of two-rowed spikes in the control and the samples of all stations in 1964 (F_9) and 1965 (F_{10}).

where two-rowed spikes increased significantly ($P < 0.05$) over the control. At Fort Simpson and Whitehorse selection pressure was so strong against two-rowed spikes that after five years of cultivation their proportion dropped from 24.43 per cent to 2.17 and 5.82 per cent respectively. Proportion of two-rowed spikes was also lower than the control in the samples of Davis and Edmonton.

Awn type

Figure 11 (page 38) shows the percentages of rough awns in the samples of all stations in 1964 and 1965. The analysis of variance is given in Table 12. Proportion of rough awns in samples of Fort Simpson was found significantly higher ($P < 0.05$) than that of the control. No difference was observed between the results of the control and of the samples obtained from Whitehorse, Beaverlodge, Edmonton, Lacombe and Vollebekk. Percentages of rough awns were similar in the samples of Lethbridge, Davis and Whitehorse; and of Beaverlodge, Vollebekk and Fort Simpson. Lowest percentage of rough awns was found in the sample of Pullman (32.44 per cent) and the highest in the sample of Fort Simpson (73.90 per cent).

Year variance was found non-significant, which indicates that the percentages of rough awns, taken over all stations, were not significantly different in the two seasons.



1 = Fort Simpson
2 = Whitehorse
3 = Vollebekk
4 = Beaverlodge

5 = Edmonton
6 = Lacombe
7 = Lethbridge

8 = Pullman
9 = Davis
10 = Control

Figure 11. Percentage of rough awns in the control and the samples of all stations in 1964 (F_9) and 1965 (F_{10}).

Table 12. Analysis of variance for the average percentage of rough awns of barley grown in 1964 and 1965.

Source of variation	D.F.	M.S.	F calculated	Table value of F	
				5%	1%
Station	9	119.62	6.17**	3.18	5.35
Year	1	18.98	0.98	5.12	10.56
Error	9	19.38			
Total	19				

8 7 9 2 6 10 5 4 3 1

Shape of basal rachis internode

No significant differences were observed among the results of the samples from various stations for the shape of basal rachis internode (Appendix VII, page 82). Year variance was also found non-significant except for the long-straight type which was found significant at the 5 per cent level of probability.

Collar type

Significant ($P < 0.05$) differences were observed (Table 13) among the results of the samples of different stations for closed and V-shaped collars. For the open collar type, differences among the results of various samples were non-significant; but a significant ($P < 0.05$) difference was found for this character between two years. The proportion of closed collar in the sample of Fort Simpson was significantly ($P < 0.05$) lower than in other samples (Appendix VII, page 81). For V-shaped collar,

Table 13. Analysis of variance for the average percentage of collar types of barley grown in 1964 and 1965.

Source of variation	D.F.	Collar type					
		Closed		Open		V-shaped	
		M.S.	F	M.S.	F	M.S.	F
Station	9	70.61	3.24*	24.44	0.80	64.56	4.63*
Year	1	7.23	0.33	164.39	5.37*	88.24	6.33*
Error	9	21.81		30.60		13.93	
Total	19						
S.E.M.		4.67				3.73	

the proportion was very high in the sample of Fort Simpson. Significant differences among the samples of some other stations were also found, but the differences in collar types observed among the tillers of the same plant question the reliability of observational data.

Neck shape

Table 14 shows the analysis of variance for neck shape. For straight and curved neck shapes both station and year variances were found significant ($P < 0.05$). However, no significant differences were observed for snaky neck.

Percentage of straight neck was found significantly ($P < 0.05$) lower in the samples of Whitehorse, Fort Simpson, Lacombe, Pullman and Edmonton as compared to the control (Appendix VII, page 81). In 1964 the proportions of curved neck in samples of all stations were found significantly ($P < 0.05$) higher than the control, but in 1965 it was lower in the samples of Beaverlodge, Vollebekk and Lethbridge. Significant differences were also observed among other samples, but these must be

judged relative to the very high variation found from year to year. Differences in neck shapes, especially for straight and curved neck were observed among the tillers of the same plant; therefore, this character does not fall into a distinct genetic class and seems to be affected by environmental conditions to a great extent.

Table 14. Analysis of variance for the average percentage of neck shapes of barley grown in 1964 and 1965.

Source of variation	D.F.	Neck shape					
		Straight		Curved		Snaky	
		M.S.	F	M.S.	F	M.S.	F
Station	9	94.85	3.23*	51.09	3.98*	49.66	2.19
Year	1	540.08	18.41**	586.12	45.61**	0.06	0.002
Error	9	29.34		12.85		22.68	
Total	19						
S.E.M.		5.42		3.59			

Neck length

No significant differences for this character were observed among the results of the samples related to the various stations (Appendix VII, page 82).

Leaf width

The measurements taken on leaf width were not precise enough to warrant statistical analysis. Considerable variation, especially for broad and medium leaf width, was observed between the two years (1964 and 1965). Comparisons of means showed that the proportion of narrow leaf tended to decrease in the samples of Fort Simpson, Whitehorse, Edmonton, Lethbridge and Pullman as compared to the control (Appendix VII, page 82). Considerable increase in the proportion of narrow leaf was found in the

Heading date

Significant ($P < 0.05$) differences were observed for heading date among the results of the samples of various stations (Table 15). High year variance shows that there was considerable fluctuation between years within the samples of some stations. Station x year interaction was also found highly significant ($P < 0.01$) which indicates heterogenity of the population and/or the influence of environmental factors. Because of a very high station x year variance the standard error of difference between two adjacent means was found very high and comparison of means by this standard error did not show significant differences among the various samples. Therefore, differences between means were tested against standard error of individual means by applying the t test. No significant difference was observed between the heading period of the control and of the samples obtained from Whitehorse, Fort Simpson, Pullman and Davis (Appendix VII, page 83). Samples from Beaverlodge, Edmonton, Lacombe, Lethbridge and Vollebekk headed significantly ($P < 0.05$) later than the control.

Table 15. Analysis of variance for the average number of days from seeding to heading of barley grown in 1964 and 1965.

Source of variation	D.F.	M.S.	F calculated	Table value of F 5%	Table value of F 1%
Station	9	1,741.61	3.28*	3.18	5.35
Year	1	73,704.74	138.74**	5.12	10.56
Station x year	9	531.28	14.56**	1.90	2.46
Error	3,835	36.49			
Total	3,854				

Height of plant

Significant differences were observed for plant height among the samples of various stations and between years (Table 16). Because of greater year to year variation and station x year interaction, the standard error of difference between two adjacent means was found to be very high. Despite the significant variance, no significant differences were found among the means of the samples when tested against the standard error as calculated from the station x year mean square. Therefore individual standard error of means were used for testing the differences among the means by applying the t test.

Table 16. Analysis of variance for the average height of barley plants in cm, grown in 1964 and 1965.

Source of variation	D.F.	M.S.	F calculated	Table value of F 5%	Table value of F 1%
Station	9	8,863.75	3,86*	3.18	5.35
Year	1	156,290.98	68.45**	5.12	10.56
Station x year	9	2,297.82	17.98**	1.90	2.46
Error	3,894	127.82			
Total	3,913				

Samples from Davis were found significantly shorter, and those from Fort Simpson, Beaverlodge, Edmonton, Lacombe, Lethbridge and Vollebekk, significantly taller, than the control (Appendix VII, page 83). No difference was found for the height of plant among the samples of control, Whitehorse and Pullman.

Number of tillers per plant

No significant differences were observed among the results of the samples of various stations for average number of tillers per plant (Appendix VII, page 83). Considerable differences were observed between the two years, e.g. average number of tillers in the sample from Whitehorse was 12.48 in 1964 but only 7.87 in 1965. Station x year interaction was also found highly significant ($P < 0.01$), which indicates a strong influence of environmental factors upon the average number of tillers per plant.

Yield per plant

No significant differences were found among the results of the samples of different stations for the average yield per plant (Appendix VII, page 83). Year variance was also found non-significant, indicating no significant difference between the two years within the samples of the same stations. Despite the non-significant station and year variances, station x year interaction was found highly significant ($P < 0.01$) which shows heterogeneity of the population and/or greater dependence of yield character upon environmental factors.

3. Progressive Generation Test

In the preceding two sections emphasis was given only on the population of final generations (F_9 and F_{10}) of each station. This section reports results of studies on the behaviour of certain characters in successive generations, the seeds of which were available (listed in Table 3).

Heading date

Average number of days from seeding to heading for all successive generation samples, in 1964 and 1965, is given in Table 17. Analyses of variance for heading date is given in Tables 18 and 19 for 1964 and 1965 respectively. In both years significant ($P < 0.01$) differences were observed among the results of various samples for the average number of days from seeding to heading. Differences were also found in the same generation between the two years. In 1964, the early heading types were F_7 of Davis and Whitehorse and F_6 of Edmonton. No difference was observed in the heading period of the samples from Edmonton (except F_7) and those from Beaverlodge. Of the late heading types the F_6 and F_8 of Whitehorse, F_7 of Edmonton and F_6 of Fort Simpson only the latter headed significantly later than the control.

In 1965 all samples of Whitehorse, Davis and Fort Simpson (except F_7) headed significantly ($P < 0.05$) earlier than the control. The F_8 and F_{10} of Beaverlodge and F_{10} of Edmonton were the last to head. No significant differences were observed among the results of the samples of Edmonton and of Beaverlodge for heading date.

Table 17. Average number of days from seeding to heading of barley for successive generation samples of certain stations, grown in 1964 and 1965.

Station		1964 Days to head	Code no.	1965 Days to head	Code no.
Edmonton	- F_4*	52.0	1 (control)	-	
	- F_5	51.0	2	63.2	1' (control)
	- F_6	48.7	3	63.4	2'
	- F_7	56.3	4	63.0	3'
	- F_8	54.0	5	63.2	4'
	- F_9	52.7	6	63.6	5'
	- F_{10}	-		64.0	6'
Beaverlodge	- F_5	54.0	7	-	
	- F_6	-		63.0	7'
	- F_7	54.0	8	-	
	- F_8	53.7	9	64.2	8'
	- F_9	51.7	10	63.6	9'
	- F_{10}	-		64.8	10'
Whitehorse	- F_6	57.3	11	-	
	- F_7	48.7	12	59.8	11'
	- F_8	56.7	13	57.4	12'
	- F_9	55.0	14	58.8	13'
	- F_{10}	-		57.0	14'
Fort Simpson	- F_6	62.0	15	-	
	- F_7	-		63.2	15'
	- F_9	54.0	16	-	
	- F_{10}	-		59.8	16'
Davis	- F_7	47.0	17	-	
	- F_8	-		60.6	17'
	- F_9	53.0	18	-	
	- F_{10}	-		60.8	18'

* F_3 control when grown for comparison became F_4.

Table 18. Analysis of variance for the average number of days from seeding to heading of barley grown in 1964.

Source of variation	D.F.	M.S.	F calculated	Table value of F 5%	1%
Station	17	36.58	3.60**	1.95	2.58
Block	2	98.91	9.74**	3.28	5.29
Error	34	10.16			
Total	53				

17	12	2	10	1	6	18	9	5	14	4	13	11	15
	3							7					
								8					
								16					

Table 19. Analysis of variance for the average number of days from seeding to heading of barley grown in 1965.

Source of variation	D.F.	M.S.	F calculated	Table value of F 5%	1%
Station	17	29.17	18.64**	1.79	2.28
Block	4	1.19	0.76	5.69	13.63
Error	68	1.57			
Total	89				

14'	12'	13'	11'	17'	18'	3'	1'	2'	5'	6'	8'	10'
			16'			7'	4'		9'			
							15'					

Height of plant

The average height of plant in cm for all successive generation samples is given in Table 20. Observations were taken only in 1964. Table 21 shows the analysis of variance for the average height of plant. Station variance was found highly significant ($P < 0.01$) which indicates significant differences for plant height among the various samples.

No significant difference was observed among the samples from Edmonton (F_4, F_5, F_6, F_7, F_8 and F_9) and those from Beaverlodge for plant height. The average plant height of the control and F_7, F_8 and F_9 of Whitehorse did not differ significantly from one another. The F_6 of Whitehorse was tallest single sample among all of the progressive generations.

No difference was observed for plant height among the results of the control and the samples obtained from Davis. Plant height of F_6 of Fort Simpson was significantly ($P < 0.05$) taller than the control; although no difference was found between the results of the control and F_9 of Fort Simpson. Average plant height of the samples of Davis was lowest and that of Beaverlodge highest among all of the progressive generation samples.

Maturity date

The average number of days from seeding to maturity for all successive generation samples is given in Table 22. Significant ($P < 0.01$) differences were found among the results of various samples for the maturity period (Table 23). No difference was observed among the F_5, F_7, F_8 and F_9 of Edmonton and the control (F_4) for maturity period;

Table 20. Average height of barley plants for successive generation samples of certain stations, grown in 1964.

Station		Code no.	Height, cm
Edmonton	- F_4	1 (control)	84.0
	- F_5	2	83.6
	- F_6	3	83.8
	- F_7	4	90.2
	- F_8	5	86.2
	- F_9	6	87.3
Beaverlodge	- F_5	7	89.0
	- F_7	8	87.3
	- F_8	9	88.7
	- F_9	10	89.1
Whitehorse	- F_6	11	97.1
	- F_7	12	81.6
	- F_8	13	84.0
	- F_9	14	80.9
Fort Simpson	- F_6	15	94.4
	- F_9	16	83.8
Davis	- F_7	17	79.8
	- F_9	18	81.2

Table 21. Analysis of variance for the average height of barley plants in cm, grown in 1964.

Source of variation	D.F.	M.S.	F calculated	Table value of F 5%	1%
Station	17	66.64	4.14**	1.95	2.58
Block	2	150.54	9.36**	3.28	5.29
Error	34	16.09			
Total	53				

17	14	18	12	2	3	1	5	6	9	7	10	4	15	11
					16	13		8						

although F_6 of Edmonton matured significantly earlier than the control. Similarly no difference was observed among the results of the maturity of F_5, F_7, F_8 and F_9 of Beaverlodge and the control, although considerable difference was found between F_5 and F_8 of this location.

No difference was observed between the maturity date of the control and of the samples obtained from Davis, Whitehorse and Fort Simpson; but significant ($P < 0.05$) difference was found between the results of the F_6 and F_9 of Fort Simpson.

Table 22. Average number of days from seeding to maturity of barley for successive generation samples of certain stations, grown in 1964.

Station		Code no.	Number of days
Edmonton	- F_4	1 (control)	103.3
	- F_5	2	102.3
	- F_6	3	92.7
	- F_7	4	109.0
	- F_8	5	109.0
	- F_9	6	100.7
Beaverlodge	- F_5	7	109.0
	- F_7	8	100.3
	- F_8	9	97.7
	- F_9	10	99.0
Whitehorse	- F_6	11	112.0
	- F_7	12	105.7
	- F_8	13	114.0
	- F_9	14	109.7
Fort Simpson	- F_6	15	114.0
	- F_9	16	98.7
Davis	- F_7	17	97.3
	- F_9	18	106.3

Table 23. Analysis of variance for the average number of days from seeding to maturity of barley grown in 1964.

Source of variation	D.F.	M.S.	F calculated	Table value of F 5%	Table value of F 1%
Station	17	118.12	3.87**	1.95	2.58
Block	2	309.13	10.14**	3.28	5.29
Error	34	30.50			
Total	53				

3	17	9	16	10	8	6	2	1	12	18	4	14	11	13
											5			15
											7			

Yield per plot

Average yield per plot for all successive generation samples is given in Table 24. Significant ($P < 0.01$) differences among the various samples for yield per plot were observed in 1964 (Table 25), but in 1965 differences were found to be non-significant.

For most of the samples from Whitehorse and Fort Simpson very low yield was observed in 1964. No significant differences were observed among the yields of F_4, F_5, F_6, F_7, F_8 and F_9 of Edmonton. However, the F_7 of Edmonton gave the highest yield. The F_6 and F_8 of Whitehorse and F_6 of Fort Simpson gave significantly lower yield than the control. No significant difference was observed between the results of the control and of the samples of Edmonton, Beaverlodge and Davis. It appears from the high degree of variation in yield from generation to generation of the same stations, that environmental factors such as soil heterogeneity and climatic conditions have great influence upon average yield per plot.

Table 24. Average yield of barley per plot (2 rod-rows) for successive generation samples of certain stations, grown in 1964 and 1965.

Station		1964		1965	
		Yield, gm	Code no.	Yield, gm	Code no.
Edmonton	- F_4	720	1 (control)	-	
	- F_5	738	2	1005	1' (control)
	- F_6	712	3	1002	2'
	- F_7	850	4	1036	3'
	- F_8	780	5	1008	4'
	- F_9	750	6	936	5'
	- F_{10}	-		914	6'
Beaverlodge	- F_5	812	7	-	
	- F_6	-		1035	7'
	- F_7	733	8	-	
	- F_8	798	9	1004	8'
	- F_9	815	10	1005	9'
	- F_{10}	-		1001	10'
Whitehorse	- F_6	133	11	-	
	- F_7	568	12	979	11'
	- F_8	508	13	971	12'
	- F_9	567	14	963	13'
	- F_{10}	-		942	14'
Fort Simpson	- F_6	457	15	-	
	- F_7	-		943	15'
	- F_9	750	16	-	
	- F_{10}	-		963	16'
Davis	- F_7	640	17	-	
	- F_8	-		1042	17'
	- F_9	720	18	-	
	- F_{10}	-		984	18'

Table 25. Analysis of variance for the average yield of barley per plot in gm, grown in 1964.

Source of variation	D.F.	M.S.	F calculated	Table value of F 5%	Table value of F 1%
Station	17	90,326.28	12.99**	1.95	2.58
Block	2	55,428.24	7.97**	3.28	5.29
Error	34	6,953.24			
Total	53				

11 15 13 14 12 17 3 1 8 2 6 5 9 7 10 4

18 16

Proportion of black kernels

The average percentage of black kernels in the successive generation samples of all stations whose seeds were available are shown in Figures 12 and 13 (pages 55 and 56). It appears that there was gradual reduction in the proportion of black kernels, in successive generations, at all stations.

The percentage of black kernels in the original bulk (F_3) was 7.42, but none of the F_{10} samples contained more than one per cent except that of Whitehorse. In the F_5 generation of Whitehorse the percentage of black kernel was 1.71 but in the F_6 it increased to 10.29 and in the F_7 it again decreased to 2.78. After little fluctuation in the F_8 and F_9, in the F_{10} 3.30 per cent of black kernels were found. At all other stations sharp reduction in the proportion of black kernels

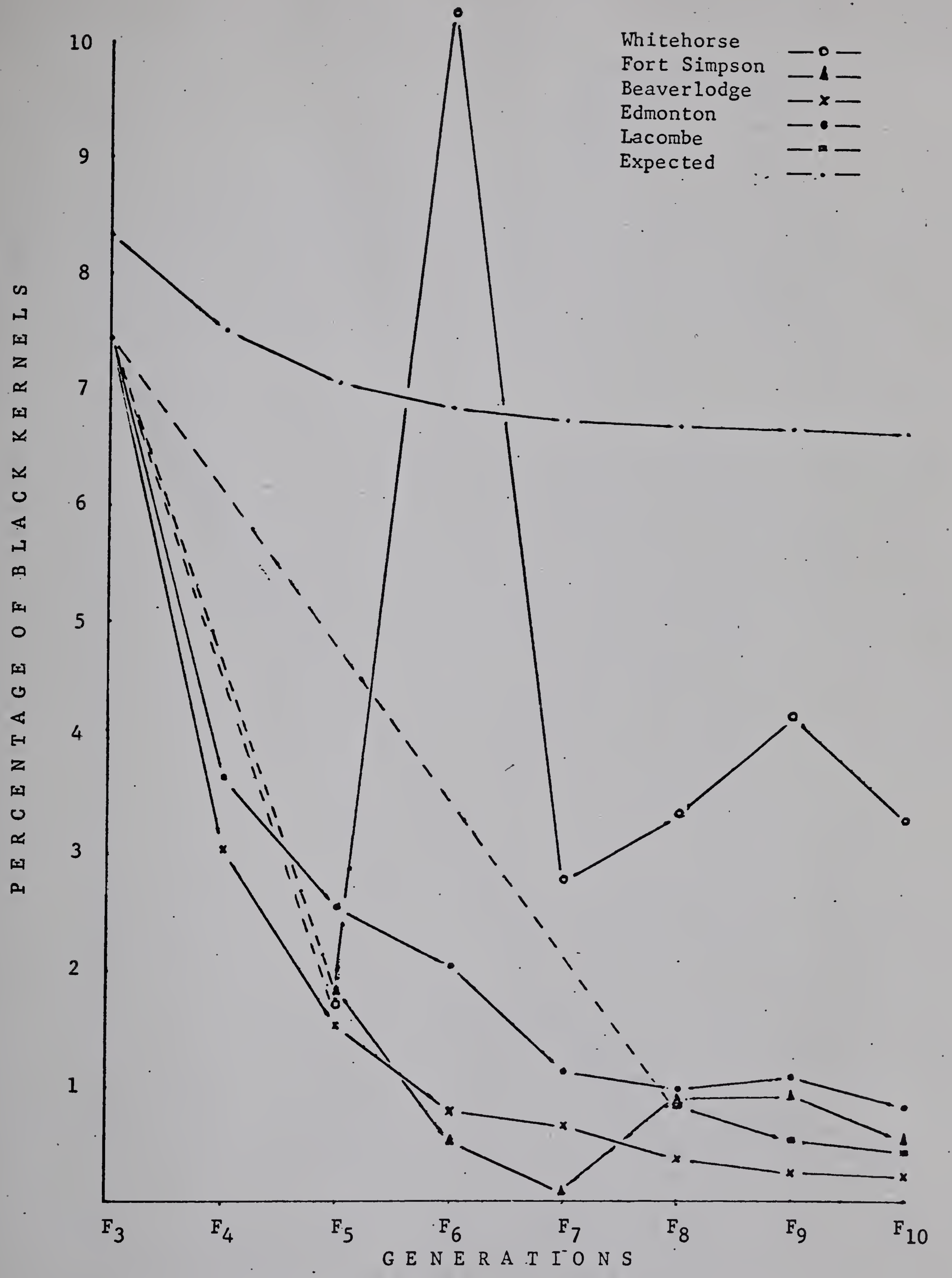


Figure 12. Percentage of black kernels in successive generation samples of certain stations.

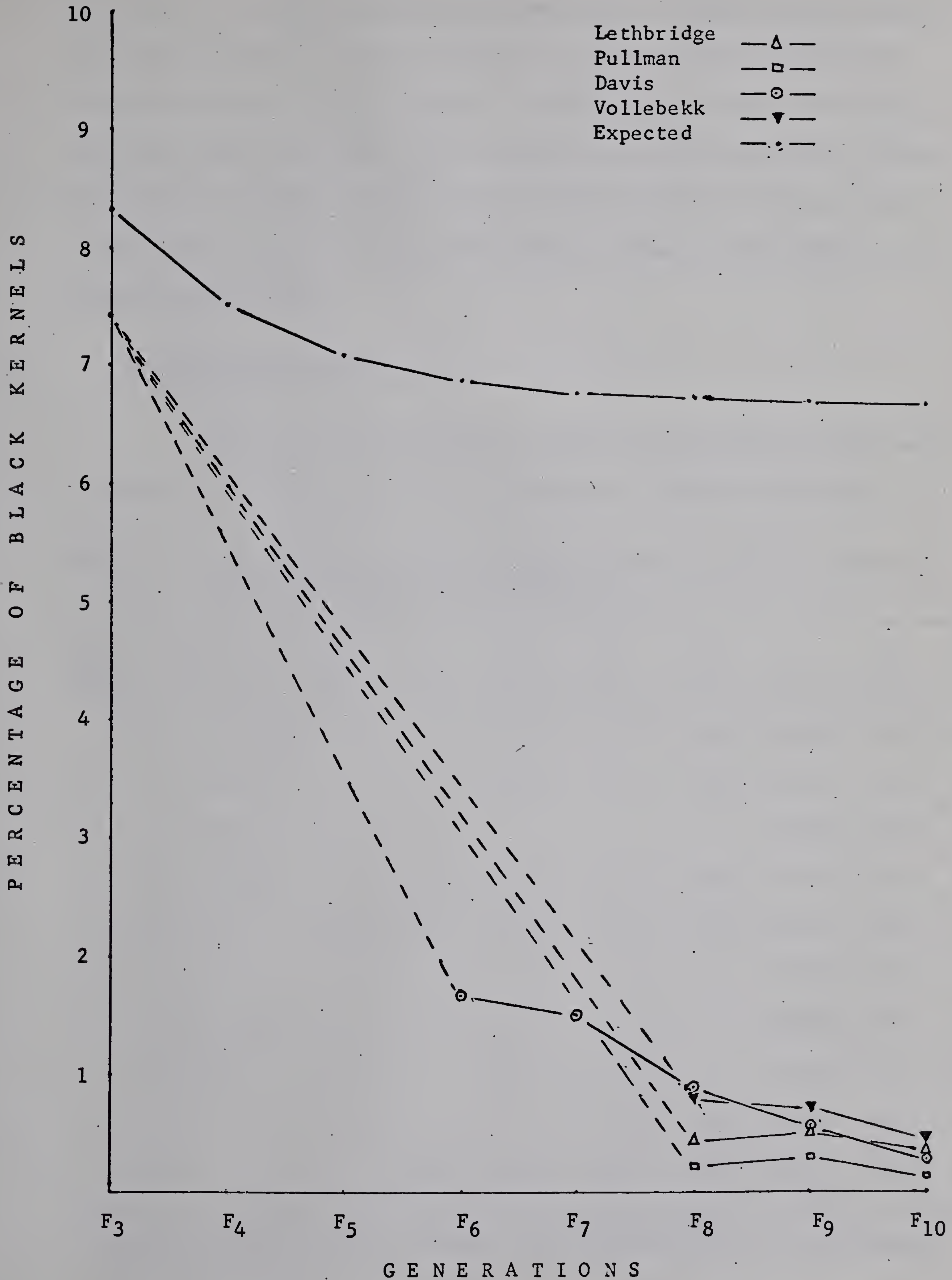


Figure 13. Percentage of black kernels in successive generation samples of certain stations.

was observed. In later generations elimination of black kernels became very slow as shown in Figures 12 and 13. Rate of elimination at some stations was faster than at others. In the F_{10} of Pullman, Beaverlodge and Davis only 0.171, 0.225 and 0.290 per cent black kernels were found, respectively. However, 3.303, 0.811, 0.587 and 0.474 per cent of black kernels were found in the F_{10} of Whitehorse, Edmonton, Fort Simpson and Lacombe, respectively.

Thousand kernel weight

The average thousand kernel weight, based on one to three years of observation in the samples of all stations is given in Table 26.

Table 26. Average thousand kernel weight of barley in gm for successive generation samples of all stations.

Code no.	Station	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
1	Fort Simpson	-	-	31.10/	35.49	33.10	37.20/	36.18	33.24
2	Whitehorse	-	-	24.80/	35.97	34.10	34.89	36.37	36.70
3	Vollebekk	-	-	-	-	-	33.80/	37.08	34.07
4	Beaverlodge	-	29.50/	38.20	33.97	36.17	34.55	34.28	34.65
5	Edmonton	40.00	38.37	36.67	36.04	35.64	35.81	35.17	34.52
6	Lacombe	-	-	-	-	-	35.21/	33.15	35.15
7	Lethbridge	-	-	-	-	-	38.60/	41.17	38.33
8	Pullman	-	-	-	-	-	31.40/	41.32	38.15
9	Davis	-	-	-	37.10/	39.26	34.13	43.32	38.67
-	Mean	-	33.94	32.69	35.71	35.65	35.07	37.56	35.94

/ Thousand kernel weight determined from samples grown at the different stations.

The regression coefficients for thousand kernel weight over generation were found non-significant except for Edmonton samples. At Edmonton there has been gradual reduction ($b = -0.68$) in the thousand kernel weight with the advance in filial generation. Some of the harvested samples obtained from Whitehorse (F_5), Fort Simpson (F_5) and Beaverlodge (F_4) were frozen, resulting in a lowering of thousand kernel weights.

Selection trend of various characters at Edmonton

Figure 14 shows the trend of heading date, height of plant, maturity date, yield per plot (2 rod-rows), thousand kernel weight and black kernels in successive generations (F_5 to F_9) at Edmonton as compared to the control (F_4). It appears that there were positive associations in the trends of heading date, height of plant, maturity date and yield per plot; however, there was some random fluctuation from generation to generation. The regression coefficient ($b = -0.68$) calculated for thousand kernel weight was found significant which shows there has been gradual reduction in the kernel weight with the advance in filial generation. Sharp reduction in the percentages of black kernels occurred with advancing generations. In F_9 percentage of black kernels was only 29.9 of the control (F_4). Since observations on maturity date and height of plant were not possible due to lodging in 1965, the F_{10} generation is not included in Figure 14.

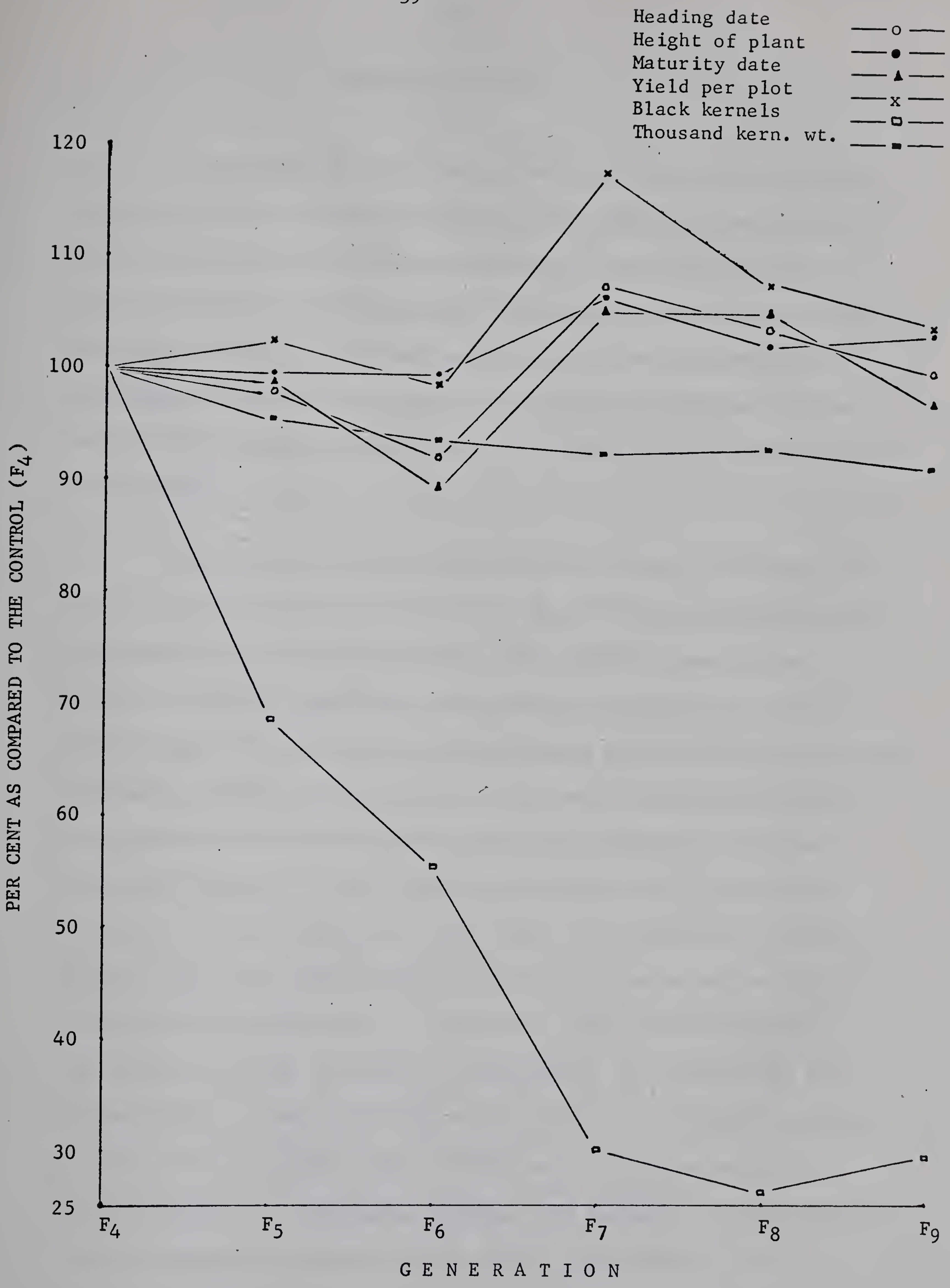


Fig. 14. Selection trend of various characters in successive generations at Edmonton (F_5 to F_9) as compared to the control (F_4), grown in 1964.

GENERAL DISCUSSION

The purpose of the investigation reported in this thesis was to study the effect of natural selection in segregating generations of bulked barley hybrids at different stations. The stations, where material was grown (Fig. 1), provide a wide range of latitude, altitude, day length, precipitation, temperature, etc. It was presumed that differences in the factors of natural selection at different stations would favour different genotypes and would change the genetic composition of the composite cross.

Difference in heading period among the samples obtained from different stations can be attributed to the differences in environmental conditions of the stations concerned. For instance, samples from Whitehorse and Fort Simpson were the earliest heading type. This is partly because of the short frost-free growing period where late maturing types were eliminated by early frost, thus early types were favoured. In this way selection directed the population towards early heading types and consequently, the composite population after five years of cultivation consisted mostly of these types. In addition to the short growing period other environmental factors may also be responsible for favouring early heading type, as the sample from Davis also headed significantly earlier than most of the samples. The reverse was true at Beaverlodge, Lacombe and Edmonton where natural selection was acting in favour of late heading types. Differences in heading date in different species of _Potentilla_, _Horkelia_ and _Achillea_ at three altitudes have been reported by Clausen _et al_. (1940, 1948, 1958).

The control samples were in F_4 and F_5 generations in 1964 and 1965 respectively. Their earliness seems to be due to the dominance of earliness over late types (Aksel and Johnson, 1961). Differences in heading date within the samples of same stations were observed between the two years. This was noticed mainly in the sample from Whitehorse which headed quite late in 1964 but very early in 1965. The reason for this discrepancy is not clearly understood. It is assumed that in part the change in climatic conditions and smaller number of plants per plot, which caused luxuriant growth, was responsible for delayed heading in 1964. At certain stations such as Pullman and Lethbridge natural selection favoured mid-heading types.

Results obtained for heading period in the progressive generation test are in agreement with those of bulk hybrid test. Considerable differences were observed among the samples of different generations of the same station (Tables 18 and 19, and Figure 14). The reason for this discrepancy is not clearly understood; however, it may be partly attributed to the seasonal variations.

Observations for heading date taken on an individual plant basis also show significant differences among the results of the samples from different stations. The spaced planted material headed earlier than the bulk seeded. This may be due to the fact that all individual plants had favourable growing conditions under space planting. Differences for heading period in bulked barley hybrids grown at different stations have been reported by Taylor (1951).

For plant height little difference was observed among the results of the samples obtained from different stations. Data of 1964

which were analyzed by the t test showed significant differences among the results of the samples of different stations but those of 1965 which were analyzed by calculating F values showed no significant differences. The reason for this discrepancy seems to be the method of analysis used. In the t test it was not possible to calculate out the block effect which might have caused the significant differences among the results of the samples of various stations.

Samples from Whitehorse and Davis generally were the shortest ones in both years' trial. Natural selection for shorter stature at Davis in a composite cross of barley has been reported by Allard and Jain (1962). The average plant heights of other samples were not different from one another, although considerable differences were found between two years. In 1965 plant height of all samples were 15 to 20 cm higher than 1964. This is mainly due to adequate moisture during the early growth period in 1965 with 7.48 inches of rainfall in June as compared to 1.04 in 1964.

Observations on plant height in the progressive generation and spaced-plant tests also showed significant differences among the results of the samples obtained from different stations (Tables 21 and 16). The average plant height over all samples of progressive generation and spaced-plant tests is similar to that in bulk hybrid test. Significant year variances show the high degree of dependence of this character upon environmental factors.

Respecting maturity period, considerable differences were observed among the results of the samples obtained from various stations. A high degree of association between the heading and maturity date was

found also, with few exceptions. Since the parental varieties used in the crosses differ in length of the time required from heading to maturity, lack of association between heading and maturity period observed in some cases is not surprising. The sample from Davis which headed quite early matured relatively late in both years. Dominance of long heading to ripening period over short has been reported by Aksel and Johnson (1961) which may explain the delayed maturity of early heading types.

The cloudy and wet weather from August 25 to harvest (September 9) in 1964 delayed ripening. Average number of hours of bright sunshine per day from August 25 to harvest was 3.49. The effect was noticed mainly on the Whitehorse sample which had a large number of secondary tillers because of lesser number of plants per plot (seeds used for sowing were damaged by frost). On the average the samples from Whitehorse, Fort Simpson and control matured earlier; and those of Beaverlodge and Lacombe later.

Significant differences for maturity period were found among the samples of different generations of the same station. High variability was also found within the sample of same generation. These findings are in close agreement with those of Suneson (1963). He found variability of up to 20 days in the F_{35} generation of a composite cross.

In yield highly significant differences were observed among the various samples. This is no doubt due to differences in the composite population obtained from different stations. Selection of high yielding types at one station and relatively lower at another should be attributed to the factors of localized natural selection. Nilsson-Leissner (1948),

on the bases of his studies with forage crops, stated that natural selection sorted out genotypes of forage species well adapted to the local conditions.

The association of high yield and late maturity in cereal crops has come to be generally accepted as physiologically inevitable. This may be very important in assessing the yielding capacity of the samples obtained from northern regions. Samples from Whitehorse and Fort Simpson, whose yields are relatively lower, require special attention in this respect. The average growing period at these stations is quite short. Day length is also longer than at other stations. These factors provide entirely different habitat in which high yielding types which are generally late in maturity would be eliminated. However, early maturing types whose yields are generally low may thrive quite well in northern regions. Thus natural selection may not be in the direction of breeders objectives (Wellhausen, 1954; Suneson, 1942; Sakai and Gotoh, 1955).

At certain stations especially at Lethbridge, Davis, Beaverlodge and Lacombe natural selection was found to favour high yielding types. Increase of yield in the later generation of composite-cross of barley has been reported by Harlan et al. (1940), Suneson and Stevens (1953), Suneson (1956) and Suneson and Ramage (1963). Significant linear correlation between fitness and agronomic productivity in bulked variety hybrids has been found by Jain (1961).

In 1965 the station variance in the progressive generation and in the second seeding of bulk hybrid (Table 10) tests were found non-significant. This was due to heavy lodging which caused poor

development of seeds. The progressive generation test of 1964 (Table 25) shows the significant differences among the results of the samples of various locations for average yield per plot. As in bulk hybrid test, samples from Beaverlodge and Edmonton were of high yielding types. Since most of the seeds obtained from Whitehorse and Fort Simpson were frozen, a poor stand (and consequently very low yield) was observed. From Table 24 it appears that there is a high degree of fluctuation for yield among the different generations at the same stations. This shows the preponderant influence of environmental factors.

Yield observations taken on individual plant bases show no significant differences among the samples obtained from different stations. This finding is in agreement with that of Immer (1942), who concluded that the yield of a single plant appears to be determined largely by environmental factors. Similarly no difference was found among the results of the samples of various stations for average number of tillers per plant in spaced-plant test. The reason for the non-significant differences among the results of the samples of various stations appears to rest with the space-seeding in which, unlike bulk seeding, both low and high yielding plants get equal opportunity to flourish.

Results obtained concerning the proportion of black kernels in the composite cross are of great interest. At all stations there has been selection against the black kernels. It appears that general adaptability of black kernels, although a neutral character is very poor. Its elimination from the bulk population presumes a genetic linkage with characters of low competitive ability. Rate of elimination was different at different stations. Figures 12 and 13 show the reduction in the

proportion of black kernels in successive generations at all stations. The elimination of black kernel types was very fast in the first few generations of bulk cultivation, but in later generations it was very slow. These findings are similar to those of Suneson and Stevens (1953).

The trend of elimination of black kernels was markedly different at Whitehorse as shown in Figure 12; the rate of elimination was slowest. The reason for the sudden increase in the proportion of black kernels in F_6 generation at Whitehorse is not clearly understood. It is supposed that peculiar conditions favourable for the plants with black kernels in 1959 may be partly responsible for the increase.

At other stations selection pressure was so strongly against the black kernel types that none of the samples contained more than one per cent black kernels in the F_{10} generation, as against the expected percentage of 6.68 assuming no selection pressure.

In spite of the significant differences among the results of the samples obtained from various stations for yield, no significant difference was observed for thousand kernel weights. It appears from this that kernel weight does not play a major role in determining the yield. Johnson and Aksel (1959) reported that the number of kernels per head predominates in determining yield while weight of kernel plays a minor role. The high degree of variation in thousand kernel weight within variety between years shows greater dependence of the kernel weight upon environmental factors. Frozen kernels in the samples from Whitehorse and Fort Simpson resulted in low thousand kernel weight in the F_5 of Whitehorse and F_4 of Fort Simpson.

The reason for greater fluctuation for certain characters which have been observed among the different generations of the same station (Figure 14) is not clearly understood. However, seasonal variations, soil heterogeneity and moisture content which vary from year to year may be partly responsible for this (Hartmann and Allard, 1964).

On spaced-planted material emphasis was given mainly to qualitative characters in studying their adaptability at different stations in bulk cultivation. Both disruptive and stable selections were found. Results were of considerable interest for spike and awn types.

Differential selection was observed for spike types. At certain stations especially at Whitehorse and Fort Simpson selection pressure was so against the two-rowed spikes that its proportion dropped from 24.4 per cent in control to 5.8 per cent at Whitehorse and 2.27 per cent at Fort Simpson in F_{10}. This shows that the adaptability of two-rowed spikes in northern latitudes is very poor. Proportion of two-rowed spikes was also lower at Davis and Edmonton. Poor adaptability of two-rowed spikes in general has also been reported by Harlan et al. (1940) and Suneson and Stevens (1953). At Vollebekk (Norway) the proportion of two-rowed spikes increased considerably. Since most of the cultivated barley in Scandinavian and European countries are of two-rowed types (some of which were parents of hybrids under test), increase in the proportion of two-rowed spikes at Vollebekk is not surprising.

At Beaverlodge, Lacombe, Lethbridge and Pullman the ratio of two- and six-rowed spikes remained similar to that of control.

For awn type, some workers (Harlan et al., 1940; and Suneson and Stevens, 1953) have reported that smooth awn types seem to be lower yielding than rough awn types, but in the present investigation no such association was found. The proportion of smooth awn types increased considerably at Pullman, Lethbridge and Davis; but all of the samples obtained from these locations were of a high yielding type. The recessive genes for smooth awn may have been maintained in the population if they were linked to genes that had some selective advantage.

No difference in the proportion of rough and smooth awn was observed among the results of the samples from Lacombe, Edmonton, Beaverlodge, Whitehorse and control. Considerable decrease in the proportion of smooth awn types was observed at Fort Simpson and Vollebekk. Fort Simpson and Whitehorse are located more or less at the same latitude, but the proportion of smooth awn increased at Whitehorse and decreased at Fort Simpson. The reason for this discrepancy is not clearly understood. It is possible that altitude might be playing some role in the adaptability of different awn types as Whitehorse is 2,289 feet and Fort Simpson 430 feet above sea level.

No difference was found among the results of the samples from various stations for the shape of basal rachis internode and neck length. For these two characters differences were observed among the tillers on the same plant which shows preponderant influence of environmental factors.

Station variance for closed and V-shaped collar, straight and curved neck, and narrow leaf were found to be significant; however, the high degree of variation between years questions the reliability of the significant values.

In general, acclimatization of the composite cross at different locations is quite obvious from the present investigation. The disruptive selections which have been observed for certain traits such as heading, maturity and yield appear to be due to natural selection which sorted out most suitable types at various locations. Since the process of natural selection is usually very slow, any drastic change after the five years of cultivation may not be expected. However, in the present investigation the proportion of certain neutrally adaptive traits in the composite population has decreased rapidly which seems to be due to the linkage with the characters of poor fitness.

The differences between the original stock and the final generation samples obtained from different stations show very clearly that under natural conditions a population becomes readily adapted to widely different climates. This adaptation is brought about by the natural selection which is aided by the original genetic variability present in the population as well as spontaneous mutations.

Since the environment of any crop plant varies from season to season, from locality to locality, and even from place to place in the same field, considerable fluctuation from year to year is to be expected in the yield of a variety of a self-pollinated crop. It is suggested that a composite cross in its later generation (after F_{10}) could be grown for feed, as a material of this nature would be more stable in yield from year to year in various localities (Allard, 1961; Allard and Bradshaw, 1964). There would be less scope for the cultivation of a composite cross for food and malt where uniformity of quality is a more important factor. However, in the later generation (about F_{10}) individual

plant selections can be made for the production of a desired variety by the method of pure line selection.

The introduction of a genetically diverse material such as a composite cross in various locations would enhance the production of adaptable recombinants by hybridization (Anderson and Stebbins, 1954). To increase the possibility of obtaining desired recombinants the competitive conditions under which a composite cross should be grown, at least in the first few generations, should not be too intense. Intensive selection pressure in early generations would tend to eliminate some of the potentially desirable recombinants before they get a chance to appear (Hanson, 1959a). It is suggested that the observations on certain traits should also be taken in every generation of composite cross at each station where material is being grown in order to understand more clearly the particular nature of natural selection in cereal crops.

SUMMARY AND CONCLUSION

1. Bulk populations of 105 crosses of barley were grown for five years (F_4 to F_8 inclusive) at nine stations of widely different locations under highly competitive conditions to study the effects of natural selection. Changes that may have occurred in the bulk populations were studied by growing the resulting sample from each station in 1964 and 1965 at Edmonton. Observations were taken on quantitative and qualitative characters. The stations where materials were grown had a highly significant effect in changing the composition of the bulk population.

2. Considerable increase in yield was observed in the later generations of bulk hybrids at most of the stations especially at Lethbridge, Davis, Lacombe and Beaverlodge.

3. Natural selection was found to favour early heading types at Whitehorse (Yukon Territory), Fort Simpson (N.W.T.) and Davis (California). Late heading types were favoured at Beaverlodge, Lacombe and Edmonton. Close association was observed between the date of heading and maturity dates with few exceptions.

4. Little difference was observed for plant height among the samples from different stations. A slight shift toward shorter stature was found at Whitehorse and Davis.

5. Natural selection acted strongly against black kernels indicating poor adaptability. The reason for its poor adaptability may be its linkage with characters of low competitive capacity. The rate of elimination of black kernels was different at different stations.

6. No difference was found among the samples from different stations in thousand kernel weights.

7. Differential selection was found for spike type. The proportion of two-rowed spikes decreased at Whitehorse, Fort Simpson, Davis and Edmonton; but it increased at Vollebekk (Norway). No difference in the ratio of two- and six-rowed spike was found between the control and the samples obtained from Pullman, Beaverlodge, Lethbridge and Lacombe.

8. In the samples of Pullman, Lethbridge and Davis the proportion of rough awns decreased and in that of Fort Simpson it increased significantly as compared to the control.

9. Shape of basal rachis internode and neck length were not influenced by the station at which the seed was grown. Very little difference was observed among the samples from different locations for collar-type, neck shape and leaf width.

10. No difference in the average number of tillers per plant nor the average yield per plant was observed among the samples of various stations when spaced-planted.

11. It is concluded that factors of natural selection can be very helpful in sorting out the most adaptable types from a composite cross at the localities concerned. The shift in the gene pool may not necessarily be in the direction of the breeders objectives.

REFERENCES

Aksel, R., and L.P.V. Johnson. 1961. Genetic studies on sowing to heading and heading to ripening periods in barley and their relation to yield and yield components. Can. J. Genet. Cytol. 3:242-259.

Allard, R.W. 1960. Principles of Plant Breeding. John Wiley and Sons, New York.

Allard, R.W. 1961. The relationship between genetic diversity and consistency of performance in different environments. Crop Sci. 1:127-133.

Allard, R.W., and A.D. Bradshaw. 1964. Implications of genotype-environmental interactions in applied plant breeding. Crop Sci. 4:503-508.

Allard, R.W., and S.K. Jain. 1962. Population studies in predominantly self-pollinated species. II. Analysis of quantitative genetic changes in a bulk hybrid population of barley. Evolution 16: 90-101.

Anderson, E. 1939. Recombination in species crosses. Genetics 24: 668-698.

Anderson, E. 1949. Introgressive Hybridization. John Wiley and Sons, New York.

Anderson, E., and G.L. Stebbins, Jr. 1954. Hybridization as an evolutionary stimulus. Evolution 8:378-388.

Bakhteyev, F.K. 1963. Origin and phylogeny of barley. Barley Genetics I, Proceedings of the First International Barley Genetics Symposium. Pudoc, Wageningen. pp. 1-18.

Clausen, J., and W.M. Hiesey. 1958. Experimental studies on the nature of species. Carnegie Inst. Wash. Publ. 615.

Clausen, J., D.D. Keck and W.M. Hiesey. 1940. Experimental studies on the nature of species. I. Carnegie Inst. Wash. Publ. 520.

Clausen, J., D.D. Keck and W.M. Hiesey. 1948. Experimental studies on the nature of species. III. Carnegie Inst. Wash. Publ. 581.

Cochran, W.R., and G.M. Cox. 1957. Experimental Designs. John Wiley and Sons, New York.

Darwin, C. 1859. The Origin of Species. With special introduction by Julian Huxley (1958). The New American Library of World Literature, Inc., New York.

Dobzhansky, T.G. 1951. Genetics and the Origin of Species. 3rd edition. Columbia University Press, New York.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

Fisher, R.A. 1958. The Genetical Theory of Natural Selection. Dover Publications, Inc., New York.

Florell, V.H. 1929. Bulked population method of handling cereal hybrids. J. Am. Soc. Agron. 21:718-728.

Grafius, J.E. 1959. Heterosis in barley. Agron. J. 51:551-554.

Grant, V. 1963. The Origin of Adaptations. Columbia University Press, New York.

Haldane, J.B.S. 1932. The Causes of Evolution. Longmans, London.

Hanson, W.D. 1959a. The theoretical distribution of lengths of parental gene blocks in the gametes of an F_1 individual. Genetics 44: 197-209.

Hanson, W.D. 1959b. The break up of initial linkage blocks under selected mating systems. Genetics 44:857-868.

Harlan, H.V., and M.L. Martini. 1929. A composite hybrid mixture. Agron. J. 21:487-490.

Harlan, H.V., and M.L. Martini. 1938. The effect of natural selection in a mixture of barley varieties. J. Agr. Research 57:189-199.

Harlan, H.V., M.L. Martini and H. Stevens. 1940. A study of methods in barley breeding. U.S. Dept. Agr. Tech. Bull. 720.

Harrington, J.B. 1937. The mass pedigree method in hybridization improvement of cereals. J. Am. Soc. Agron. 29:379-384.

Harrington, J.B. 1940. Yielding capacity of wheat crosses as indicated by bulk hybrid tests. Can. J. Research 18:578-584.

Hartmann, R.W., and R.W. Allard. 1964. Effect of nutrient and moisture levels on competitive ability in barley (Hordeum vulgare L.). Crop Sci. 4:424-426.

Hays, H.K., and R.J. Garber. 1927. Breeding Crop Plants. McGraw-Hill Book Co., New York.

Immer, F.R. 1941. Relation between yielding ability and homozygosis in barley crosses. J. Am. Soc. Agron. 33:200-206.

Immer, F.R. 1942. Distribution of yields of single plants of varieties and F_2 crosses of barley. Agron. J. 34:844-850.

Johnson, L.P.V. 1963. Biometrical Methods. Arya Bharati Mundranalaya. New Delhi, India.

Johnson, L,P.V., and G.I. Paul. 1958. Inheritance of earliness in barley. Can. J. Plant Sci. 38:219-233.

Johnson, L.P.V., and A.R. Taylor. 1958. Note on the effect of photoperiod and temperature on the development of spike primordia in barley. Can. J. Plant Sci. 38:122-123.

Johnson, L.P.V., and R. Aksel. 1959. Inheritance of yielding capacity in a fifteen parent diallel cross of barley. Can. J. Genet. Cytol. 1:208-265.

Johnson, L.P.V., and A.E. Eunus. 1964. Inheritance of earliness in a six-parent diallel cross of barley. Advan. Frontiers of Plant Sci. 9:111-118.

Jain, S.K. 1961. Studies on the breeding of self pollinating cereals. The Composite cross bulk population method. Euphytica 10: 315-324.

Jain, S.K., and R.W. Allard. 1960. Population studies in predominantly self-pollinated species. I. Evidence for heterozygote advantage in a closed population of barley. Proc. Nat. Acad. Sci. 46: 1371-1377.

Leonard, W.H., and J.H. Martin. 1963. Cereal Crops. Macmillan Co., New York.

Lerner, M. 1959. The concept of natural selection. A centennial view. Proc. Am. Phil. Soc. 103:173-182.

Litzenberger, S.C., and J.M. Green. 1951. Inheritance of awns in barley. Agron. J. 43:117-123.

Love, H.H. 1927. A program for selecting and testing small grains in successive generations following hybridization. J. Am. Soc. Agron. 19:705-712.

Mather, K. 1943. Polygenic inheritance and natural selection. Biol. Rev. Cambridge Phil. Soc. 18:32-64.

Murty, G.S., and K.B.L. Jain. 1959. Genetic studies in barley. I. Inheritance of pigmentation in various plant parts. J. Indian Botan. Soc. 38:561-574.

Murty, G.S., and K.B.L. Jain. 1960. Genetic studies in barley. II. Inheritance of fertility of the lateral florets and certain other characters. J. Indian Botan. Soc. 39:281-308.

Newman, L.H. 1912. Plant breeding in Scandinavia. Canadian Seed Growers' Association, Ottawa.

Nilan, R.A. 1964. The cytology and genetics of barley. Monographic Supplement No. 3, Vol. 32, No. 1. Washington State University.

Nilsson-Leissner, G. 1948. Natural selection and the breeding of cross fertilizing plants. pp. 198-210. Svalof, 1886-1946. Ed. by A. Akerman and others. Carl Blooms Boktryckeri. A-B, Lund.

Sakai, K. 1955. Competition in plants and its relation to selection. Cold Spring Harbor Symp. Quant. Biol. 20:137-157.

Sakai, K., and K. Gotoh. 1955. Studies on competition in plants. IV. Competitive ability of F_1 hybrids in barley. J. Heredity 46: 139-143.

Sheppard, P.M. 1960. Natural Selection and Heredity. Harper and Row, New York.

Simmonds, N.W. 1962. Variability in crop plants, its use and conservation. Biol. Rev. Cambridge Phil. Soc. 37:442-465.

Simpson, G.G. 1953. The Major Features of Evolution. Columbia University Press, New York.

Smith, W.E. 1960. Fertility of autotetraploid varieties and hybrids of barley. Can. J. Plant Sci. 40:434-442.

Stebbins, G.L. 1950. Variation and Evolution in Plants. Columbia University Press, New York.

Suneson, C.A. 1949. Survival of four barley varieties in a mixture. Agron. J. 41:459-461.

Suneson, C.A. 1953. Frost induced natural crossing in barley, and a corollary on stem rust persistence. Agron. J. 45:388-389.

Suneson, C.A. 1956. An evolutionary plant breeding method. Agron. J. 48:188-191.

Suneson, C.A. 1963. Breeding techniques - composite crosses and hybrid barley. Barley Genetics I. Proceedings of the First International Barley Genetics Symposium. Pudoc, Wageningen, 1963. pp. 303-309.

Suneson, C.A., and G.A. Wiebe. 1942. Survival of barley and wheat varieties in mixtures. Agron. J. 34:1052-1056.

Suneson, C.A., and H. Stevens. 1953. Studies with bulked hybrid populations of barley. U.S. Dept. Agr. Tech. Bull. 1067.

Suneson, C.A., and R.T. Ramage. 1963. Natural selection studies with barley populations featuring genetic male sterility. Advan. Frontiers of Plant Sci. 7:181-186.

Takahasi, R. 1963. Further studies on the phylogenetic differentiation of cultivated barley. Barley Genetics I. Proceedings of the First International Barley Genetics Symposium. Pudoc, Wageningen. pp. 1-18.

Taylor, L.H. 1951. Effect of natural selection in segregating generation upon bulk populations of barley. Ph.D. Thesis. Iowa State University.

Ueki, K. 1952. (In Nilan, R.A. 1964. The cytology and genetics of barley. Monographic Supplement No. 3, Vol. 32, No. 1. Washington State University.)

Wellhausen, E.J. 1954. Modern corn breeding and production in Mexico. Phytopathology 44:391-395.

Wiebe, G.A., and D.A. Reid. 1961. Classification of barley varieties grown in the United States and Canada in 1958. U.S. Dept. Agr. Tech. Bull. 1224.

Appendix I. The t values (between rows to columns) for number of days from seeding to heading for the first seeding of 1964.

	Ft. S. 1	Whit. 2	Voll. 3	Beav. 4	Edmo. 5	Laco. 6	Leth. 7	Pull. 8	Davis 9
Cont. 10	-0.19	-1.05	-2.92**	-7.78**	-3.24**	-3.57**	-2.72**	-2.07*	1.85
Davis 9	-2.26*	-4.22**	-6.03**	-14.62**	-6.63**	-6.91**	-5.76**	-5.58**	
Pull. 8	2.01	1.49	-1.48	-9.01**	-2.19*	-2.35*	-1.20		
Leth. 7	2.77**	2.41*	-0.23	-5.71**	-0.85	-0.95			
Laco. 6	3.61**	3.51**	0.71	-4.62**	-0.07				
Edmo. 5	3.47**	3.32**	0.62	-4.58**					
Beav. 4	8.32**	10.29**	5.42**						
Voll. 3	2.92**	2.64*							
Whit. 2	0.99								

1 = Fort Simpson 3 = Vollebekk 5 = Edmonton 7 = Lethbridge 9 = Davis
2 = Whitehorse 4 = Beaverlodge 6 = Lacombe 8 = Pullman 10 = Control

Appendix II. The t values (between rows to columns) for number of days from seeding to heading for the second seeding of 1964.

	Ft. S. 1	Whit. 2	Voll. 3	Beav. 4	Edmo. 5	Laco. 6	Leth. 7	Pull. 8	Davis 9
Cont. 10	-4.09**	-2.85**	-5.35**	-9.96**	-6.18**	-7.15**	-6.84**	-5.37**	-0.21
Davis 9	-3.80**	-2.59*	-5.03**	-9.47**	-5.85**	-6.80**	-6.44**	-5.06**	
Pull. 8	1.27	2.31*	0.12	-3.43**	-0.69	-1.53	-0.63		
Leth. 7	2.07*	3.21**	0.78	-3.22**	-0.14	-1.07			
Laco. 6	2.85**	3.88**	1.68	-1.79	0.83				
Edmo. 5	1.99	2.64*	0.83	-2.68*					
Beav. 4	4.93**	6.00**	3.64**						
Voll. 3	1.16	2.22*							
Whit. 2	-1.08								

Appendix III. The t values (between rows to columns) for height of plants in cm for the first seeding of 1964.

	Ft. S. 1	Whit. 2	Voll. 3	Beav. 4	Edmo. 5	Laco. 6	Leth. 7	Pull. 8	Davis 9
Cont. 10	-1.25	3.48**	-2.22*	-3.17**	-3.66**	-4.94**	-4.16**	0.67	1.68
Davis 9	-2.74**	1.67	-3.67**	-4.73**	-4.86**	-6.17**	-5.57**	-0.86	
Pull. 8	-1.17	2.46*	2.64*	-3.50**	-3.95**	-5.12**	-4.38**		
Leth. 7	2.61*	7.36**	1.66	1.23	-0.33	-1.29			
Laco. 6	3.55**	7.72**	2.72**	2.42*	0.78				
Edmo. 5	2.47*	6.28**	2.21*	1.33					
Beav. 4	1.59	6.64**	0.59						
Voll. 3	0.90	5.34**							
Whit. 2	-4.41**								

Appendix IV. The t values (between rows to columns) for number of days from seeding to maturity for the first seeding of 1964.

	Ft. S. 1	Whit. 2	Voll. 3	Beav. 4	Edmo. 5	Laco. 6	Leth. 7	Pull. 8	Davis 9
Cont. 10	0.92	-4.94**	-2.43*	-4.29**	-2.35*	-4.74**	-1.51	-2.82**	-3.66*
Davis 9	5.03**	-1.30	0.24	-0.59	1.12	-1.64	1.84	1.29	
Pull. 8	4.07**	-1.76	-0.92	-1.11	0.51	-2.03*	1.22		
Leth. 7	2.58*	-3.07**	2.14*	-2.45*	-0.74	-3.16**			
Laco. 6	6.12**	0.61	2.14*	1.21	2.56*				
Edmo. 5	3.58**	-2.40*	-0.24	-1.73					
Beav. 4	5.99**	-0.76	1.30						
Voll. 3	3.53**	-1.90							
Whit. 2	6.76**								

Appendix V. The t values (between rows to columns) for yield per plot (2-rod rows) in gm for the first seeding of 1964.

		Ft. S. 1	Whit. 2	Voll. 3	Beav. 4	Edmo. 5	Laco. 6	Leth. 7	Pull. 8	Davis 9
Cont.	10	-1.72	7.36**	-0.20	-5.49**	-4.42**	-4.95**	-6.17**	-2.52*	-3.69**
Davis	9	1.96	9.27**	3.16**	-1.69	-0.89	-1.06	-2.23*	1.53	
Pull.	8	0.59	8.78**	2.01	-3.40**	-2.42*	-2.77**	-4.04**		
Leth.	7	4.31**	10.77**	5.42**	0.49	1.20	1.20			
Laco.	6	3.12**	10.04**	4.29**	-0.67	0.09				
Edmo.	5	2.77**	9.64**	3.88**	-0.73					
Beav.	4	3.73**	10.36**	4.82**						
Voll.	3	-1.35	7.20**							
Whit.	2	-8.21**								

Appendix VI. The t values (between rows and columns) for yield per plot (2-rod rows) in gm for the second seeding of 1964.

		Ft. S. 1	Whit. 2	Voll. 3	Beav. 4	Edmo. 5	Laco. 6	Leth. 7	Pull. 8	Davis 9
Cont.	10	-1.01	4.84**	-1.46	-4.95**	-3.66**	-4.37**	-3.06**	-2.03*	-2.50*
Davis	9	1.76	7.71**	1.49	-2.29*	-1.09	-1.80	-0.44	0.60	
Pull.	8	1.19	7.43**	0.86	-3.16**	-1.81	-2.57*	-1.14		
Leth.	7	2.39*	8.56**	2.16*	-1.92	-0.66	-1.41			
Laco.	6	3.91**	10.06**	3.85**	-0.41	0.72				
Edmo.	5	3.08**	9.21**	2.93**	-1.18					
Beav.	4	4.64**	11.01**	4.70**						
Voll.	3	0.45	7.34**							
Whit.	2	-6.49**								

Appendix VII. Summary of observations taken on spaced-plant material.

Code No.	Location	Spike type in percent		Awn type in percent		Collar type in percent			Neck shape in percent		
		Two-rowed	Six-rowed	Rough	Smooth	Closed	Open	V-shape	Straight	Curved	Snaky
1964											
1	Fort Simpson	1.91	98.09	82.30	17.70	67.19	16.66	16.15	36.46	48.44	15.10
2	Whitehorse	6.38	93.62	54.55	45.45	82.83	11.11	6.06	34.35	47.47	18.18
3	Vollebekk	32.00	68.00	67.00	33.00	91.50	1.50	7.00	60.00	33.50	6.50
4	Beaverlodge	23.55	76.45	65.77	34.23	78.26	12.50	9.24	48.91	44.57	6.52
5	Edmonton	18.92	81.08	62.00	38.00	80.50	14.00	5.50	49.00	42.50	8.50
6	Lacombe	19.82	80.18	56.93	43.07	84.11	4.61	11.28	27.18	50.26	22.56
7	Lethbridge	22.88	77.12	38.77	61.23	92.35	5.10	2.55	62.76	31.12	6.12
8	Pullman	18.96	81.04	24.46	75.54	92.55	5.85	1.60	27.13	40.43	32.44
9	Davis	16.61	83.39	38.50	61.50	96.50	3.50	0.00	29.50	46.00	24.50
10	Control	24.61	75.39	55.00	45.00	97.50	1.50	1.00	56.00	26.00	18.00
1965											
1	Fort Simpson	2.43	97.57	65.50	34.50	75.50	4.00	20.50	44.00	39.00	17.00
2	Whitehorse	5.26	94.74	47.00	53.00	89.00	4.00	7.00	37.00	36.00	27.00
3	Vollebekk	35.62	64.38	73.00	27.00	87.00	5.00	8.00	75.50	13.00	11.50
4	Beaverlodge	26.03	73.97	67.69	32.31	89.75	0.00	10.25	77.44	13.33	9.23
5	Edmonton	19.87	80.13	60.00	40.00	84.50	5.00	10.50	57.00	33.00	10.00
6	Lacombe	32.33	67.67	61.09	38.91	91.37	1.07	7.56	65.96	25.40	8.64
7	Lethbridge	28.80	71.20	48.00	52.00	96.00	1.00	3.00	67.50	15.50	17.00
8	Pullman	22.58	77.42	40.42	59.58	90.97	4.25	4.78	59.05	22.87	18.08
9	Davis	14.73	85.27	53.00	47.00	93.50	3.00	3.50	56.50	23.50	20.00
10	Control	24.26	75.74	64.00	36.00	86.50	3.50	10.00	66.50	18.00	15.50

Appendix VII (continued). Summary of observations taken on spaced-plant material.

Code No.	Location	Shape of basal rachis internode (in percent)				Neck length (in percent)			Leaf width (in percent)		
		Short curved	Short straight	Long curved	Long straight	Long	Medium	Short	Broad	Medium	Narrow
1964											
1	Fort Simpson	49.48	37.50	4.17	8.85	27.60	62.50	9.90	30.23	52.07	17.70
2	Whitehorse	56.56	34.34	0.51	8.59	12.62	69.71	17.67	22.22	44.45	33.33
3	Vollebekk	85.00	10.50	3.00	1.50	32.00	46.50	21.50	30.50	45.00	24.50
4	Beaverlodge	57.06	30.98	1.09	10.87	19.02	64.68	16.30	21.73	39.14	39.13
5	Edmonton	62.00	28.50	1.50	8.00	21.00	59.50	19.50	25.00	45.50	34.50
6	Lacombe	58.46	37.95	1.54	2.05	24.10	48.21	27.69	12.30	44.63	43.07
7	Lethbridge	70.92	22.45	2.55	4.08	24.49	61.23	14.28	7.65	57.15	35.20
8	Pullman	71.29	26.06	1.59	1.06	15.96	47.87	36.17	8.51	63.83	27.66
9	Davis	75.00	23.00	1.00	1.00	11.50	61.50	27.00	4.50	41.00	54.50
10	Control	74.00	22.50	1.00	2.50	19.50	58.00	22.50	5.00	55.00	40.00
1965											
1	Fort Simpson	82.00	12.00	4.00	2.00	28.00	63.50	8.50	31.50	57.00	11.50
2	Whitehorse	70.00	28.00	1.00	1.00	24.50	59.00	16.50	22.50	56.50	21.00
3	Vollebekk	72.50	24.00	1.50	2.00	14.00	66.00	20.00	7.50	53.50	39.00
4	Beaverlodge	80.53	14.35	2.05	3.07	26.66	60.01	13.33	18.46	53.85	27.69
5	Edmonton	71.00	19.50	7.00	2.50	15.00	67.50	17.50	16.50	63.00	20.50
6	Lacombe	76.27	18.91	2.14	2.68	27.56	65.97	6.47	17.29	47.04	35.67
7	Lethbridge	67.50	30.50	1.50	0.50	20.00	71.00	9.00	14.00	65.50	20.50
8	Pullman	70.76	27.12	0.53	1.59	9.04	80.30	10.66	12.76	59.05	28.19
9	Davis	55.50	41.50	1.00	2.00	10.00	83.00	7.00	13.00	52.00	35.00
10	Control	72.00	25.50	1.00	1.50	11.00	81.50	7.50	11.00	58.00	31.00

Appendix VII (continued). Summary of observations taken on spaced-plant material.

Code No.	Location	Heading date Mean	Heading date S.D.	Height in cm Mean	Height in cm S.D.	Number of tillers Mean	Number of tillers S.D.	Yield in gm Mean	Yield in gm S.D.
1964									
1	Fort Simpson	47.97 ± .55	7.25	90.50 ± .67	9.22	9.26 ± .27	3.80	17.60 ± .54	7.50
2	Whitehorse	50.16 ± .49	6.78	84.54 ± .90	12.58	12.48 ± .42	5.95	20.81 ± .82	11.32
3	Vollebekk	52.01 ± .58	8.13	91.00 ± .86	12.11	11.39 ± .46	6.46	15.44 ± .59	8.20
4	Beaverlodge	52.24 ± .48	6.39	93.80 ± .81	11.04	11.71 ± .78	5.12	18.04 ± .58	7.84
5	Edmonton	51.13 ± .48	6.58	93.55 ± .85	12.08	11.45 ± .42	5.95	17.26 ± .55	7.70
6	Lacombe	50.18 ± .45	6.23	89.51 ± .87	12.19	10.27 ± .34	4.77	15.57 ± .51	7.09
7	Lethbridge	52.31 ± .45	6.33	93.77 ± .75	10.54	12.48 ± .54	7.55	18.86 ± .62	8.68
8	Pullman	48.14 ± .48	6.55	82.71 ± .85	11.65	11.44 ± .17	2.28	16.23 ± .57	7.79
9	Davis	46.33 ± .54	7.60	74.70 ± .83	11.68	11.33 ± .47	6.60	16.67 ± .67	9.12
10	Control	47.28 ± .49	6.90	81.28 ± .97	13.71	10.69 ± .39	5.57	12.77 ± .58	7.98
1965									
1	Fort Simpson	56.78 ± .35	4.90	101.65 ± .60	8.52	9.17 ± .23	3.30	18.34 ± .50	7.10
2	Whitehorse	53.42 ± .34	4.76	95.00 ± .74	10.56	7.87 ± .22	3.13	13.44 ± .46	6.48
3	Vollebekk	60.54 ± .34	4.76	101.00 ± .76	10.76	9.14 ± .29	4.16	14.78 ± .51	7.14
4	Beaverlodge	62.15 ± .39	5.42	99.76 ± .68	9.54	9.95 ± .35	4.86	15.99 ± .56	7.91
5	Edmonton	61.62 ± .37	5.22	103.15 ± .70	9.97	10.45 ± .31	4.43	19.40 ± .56	8.00
6	Lacombe	59.40 ± .34	4.70	105.54 ± .81	11.06	10.19 ± .32	4.36	16.10 ± .58	7.93
7	Lethbridge	58.30 ± .33	4.64	104.15 ± .83	11.76	9.20 ± .25	3.57	14.88 ± .43	6.06
8	Pullman	57.96 ± .39	5.34	98.35 ± .79	10.89	9.62 ± .30	4.19	16.18 ± .47	6.50
9	Davis	56.52 ± .41	5.79	92.50 ± .82	11.54	8.50 ± .25	3.59	15.20 ± .65	9.19
10	Control	58.54 ± .42	5.95	99.65 ± .93	13.17	9.91 ± .31	4.40	16.78 ± .58	8.21

Appendix VIII. Expected proportion of black kernels in successive generations

Filial generation	Total no. of kernels considered	Proportion of non-black (bb) kernels	Proportion of black kernels: Black (Bb)	Black BB	Total proportion of black kernels	Percentages of black kernels in the population
F_1	105	91	14	0	14	13.333
F_2	402	378	28	14	42	10.000
F_3	1,680	1,540	56	84	140	8.333
F_4	6,720	6,216	112	392	504	7.500
F_5	26,880	24,976	224	1,680	1,904	7.083
F_6	107,420	100,128	448	6,944	7,392	6.875
F_7	430,080	400,960	896	28,224	29,120	6.770
F_8	1,720,320	1,604,736	1,792	113,792	115,584	6.718
F_9	6,881,280	6,420,736	3,584	456,960	460,544	6.692
F_{10}	27,525,120	25,686,528	7,168	1,831,424	1,838,592	6.679